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LEVEL II

POLYMER TETHERLINE EVALUATION FOR BALLOON TECHNOLOGY

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Department of Civil Engineering, Engineering Mechanics and Materials
United States Air Force Academy
Colorado 80840

Final Report
1 October 1974 - 30 September 1976

30 September 1976

Approved for public release; distribution unlimited

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

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The testing summarized herein was conducted to assess the best Kevlar cable configuration for use in very high altitude tethered balloon systems, up to 65,000 feet.

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CONTENTS

3

STUDY OF BASIC STRENGTH CHARACTERISTICS

OF

SAMSON (KEVLAR 29) BRAIDED CABLE

0.3 inch diameter

32 pounds/1000 feet

12 November 1974

OBJECTIVE

To establish the basic strength characteristics of SAMSON when subjected to static and cyclic loading in straight tension and around a 90° stationary sheave.

EQUIPMENT

Tinius-Olsen 120,000 Super L Tensile test machine
Locally fabricated extension arm with 90° sheave installed
10 foot steel tape measure graduated in 1/32 inch increments

PROCEDURE

Five tests were conducted to evaluate the basic strength properties of SAMSON. The tests are defined below, with a brief explanation concerning deviations from the initial test schedule. The following information applies to all tests:

1. A "dead side tuck" splice was used to terminate all samples. The strength of this splice, developed at USAFA, exceeds the break strength of the cable in static loading, allowing the cable failure to occur in the main section of the cable. Thus end effects on data are minimized.

2. Elongation measurements were taken over a 24 inch gage length minimum, with a steel rule graduated in 1/32 inch increments. Maximum error in measurements would therefore be less than 0.15%. Most elongation measurements were discontinued at 7000 lb load due to the distinct possibility of cable failure prior to reaching an 8000 lb load.

3. All data plots were performed on an HP-9830 computer using polynomial regression to achieve a least-square fit. In all cases a third degree polynomial was selected. Break strength was recorded directly from the testing machine and is therefore as accurate as the machine calibration. However, percent elongation at failure, extracted from the upper region of the data plots beyond 7000 lb, are only as accurate as the fit of the polynomial. This data should be used as an approximation only with error on the order of 10%.

4. All tests were performed at an ambient room temperature of 70° ± 5° F.

5. The outer nylon jacket was removed from the core for all tests.

6. Preconditioning consisted of cycling the cable 10 times from 0 to 4000 lb load.

7. Cable lengths were selected to allow the gage length to be sufficiently removed from the splice to minimize end effects.

TEST 1

Five cable samples were pulled to failure under a linearly increasing load that reached rated break strength in 10 minutes (Figure 1). After each sample was installed in the crosshead, a gage length was marked on the cable and the steel rule was attached. Elongation data in the zero load row indicates elongation due to work stretching during the preconditioning phase. Gage length is the initial length of cable during testing after preconditioning.

	Load (1000 lb)	Elongation (32nd inch)	Elongation (%)
#1	0	(20)	(2.6)
24 5/8"	1	6	.76
gage	2	10	1.27
	3	14	1.78
	4	18	2.28
	5	21	2.66
	6	24	3.05
	7	28	3.55
	7.74 failure		
#2	0	(18)	(2.34)
24 5/8"	1	6	.76
gage	2	10	1.27
	3	14	1.78
	4	18	2.29
	5	22	2.80
	6	24	3.05
	7	28	3.56
	8	30	3.82
	8.14 failure		
#3	0	(18)	(2.34)
24 9/16"	1	10	1.27
gage	2	14	1.78
	3	18	2.29
	4	21	2.67
	5	24	3.05
	6	27	3.44
	7	31	3.94
	7.78 failure		

	Load (1000 lb)	Elongation (32nd inch)	Elongation (%)
#4	0	(18)	(2.34)
24 9/16"	1	8	1.03
	2	12	1.53
	3	16	2.04
	4	19	2.42
	5	22	2.80
	6	26	3.31
	7	28	3.56
	7.83 failure		
#5	0	(18)	(2.34)
24 9/16" gage	1	9	1.15
	2	11	1.40
	3	14	1.78
	4	18	2.29
	5	22	2.80
	6	26	3.30
	7	28	3.56
	7.52 failure		

STATISTICS - Test 1

Maximum Failure Load:	8140 lb
Minimum Failure Load:	7520 lb
Average Break Strength:	7802 lb
Average Elongation at Failure	1.04 inch 4.23 %

COMMENTS - Test 1

1. Elongation from 0-1000 lb load is non-linear. It appears that fiber alignment with the load accounts for the additional stretch in this region. Elongation from 1000-6000 lb load is very consistent and predictable, at an approximate rate of 4.8×10^{-3} inch per inch per 1000 lb. The cable appears to stiffen over 6000 lb load and rate of elongation decreases.

2. All test samples but #5 failed in the main body of the cable. There is no audible warning of impending failure. The failure is clean, through all strands (occasionally one strand does not fail).

3. Hockling is noticeable in the eyelets after failure. This hockling is most likely caused by the snap back of the cable at failure. Approximate energy of snap back is

1/3 x 7800 x 6 x ,04234 = 660 foot lbs.

4. Failure loads in this test are lower than in Test 2 and significantly lower than Test 4. The manufacturer's splicing technique during continuous cable construction should be investigated as a possible cause of this wide variance of break strength, since the strength of the cable seems to be increasing as tests progress and cable is unspooled from the reel.

5. Average break strength is based on the average of all five tests, not on the average of high and low values in three test samples.

6. Data 1a lists the polynomial regression data for the minimum and maximum failure loads for Test 1. Figure 1a plots this data, with the curve associated with the minimum failure load in red. Data 1b lists all the data points acquired during Test 1, which is used to plot Figure 1b, a nominal load-elongation curve for low rate straight tension loading to failure.

TEST 2

Five cable samples were pulled to failure under a linearly increasing load that reached rated break strength within one minute (Figure 2). Test procedure was the same as in Test 1. Preconditioning was accomplished but elongation during preconditioning was not measured.

	Load (1000 lb)	Elongation (32nd inch)	Elongation (%)
#1	1	4	.52
24"	2	8	1.04
gage	3	12	1.56
	4	15	1.95
	5	20	2.60
	6	24	3.13
	8.06 failure		
#2	.5	2	.26
24"	1	5	.65
gage	2	10	1.30
	3	13	1.69
	4	17	2.21
	5	21	2.73
	6	24	3.13
	7	29	3.78
	8.46 failure		

8

	Load (1000 lb)	Elongation (32nd inch)	Elongation (%)
#3	.5	1	.13
24"	1	10	1.30
gage	2	14	1.82
	3	18	2.34
	4	22	2.86
	5	26	3.39
	6	30	3.90
	7	34	4.43
	8.66 failure		
#4	0	0	0
24"	.5	1	.13
gage	1	2	.26
	2	6	.78
	3	10	1.30
	4	14	1.82
	5	18	2.34
	6	22	2.86
	7	26	3.39
	7.70 failure		
#5	0	0	0
24"	.5	1	.13
gage	1	4	.52
	2	9	1.15
	3	13	1.69
	4	17	2.21
	5	20	2.60
	6	25	3.26
	7	29	3.78
	7.89 failure		

COMMENTS - Test 2

1. All failures occurred near the end of the buried tail in the upper splice. It appears that the splice is adequate under slow load application, but inadequate during rapid loading. The difference is most likely caused by decreasing time during which the splice can smoothly distribute the load throughout the region of the splice. The tail is trying to pull out of the cable center, while the cable is squeezing against the tail and trying to move in the opposite direction. During slow loading, this motion can be accommodated, but during rapid loading, the load build-up just away from the tail (the weakest part of the splice, Figure 2) can not distribute itself toward the eyelet, so failure occurs at that point.

9

2. Data 2a lists the regression data associated with the minimum and maximum failure loads for Test 2. Figure 2a plots this data, minimum failure load in red. Data 2b lists all data acquired in Test 2, which plots in Figure 2b as a nominal load-elongation curve for high rate straight loading to failure.

TEST 3

Six cable samples were subjected to varying degrees of cyclic loading. Test 3 as defined in the original test program was modified to allow an analysis of extreme cyclic loading on the cable. Six cable samples were tested. Two samples were loaded at 4000 lb ± 1000 lb for 500 cycles, two samples at 4000 lb ± 2000 lb for 500 cycles, and two samples at 4000 lb ± 3000 lb (both of these samples failed prior to reaching 500 cycles). The first four samples were subjected to Test 1 loading to failure after cycling.

	Load (1000 lb)	Elongation (32nd inch)	Elongation (%)
#1	.5	4	.35
36"	1	8	.69
gage	2	12	1.04
5 cpm	3	16	1.39
	4	20	1.74
	5	24	2.08
	6	28	2.43
	7	32	2.78
	8.33 failure		
#2	1	4	.35
36"	2	8	.69
gage	3	12	1.04
5 cpm	4	15	1.30
	5	19	1.65
	6	23	2.00
	7	25	2.17
	7.86 failure		
#3	.5	2	.17
36"	1	4	.35
gage	2	8	.69
2.5	3	12	1.04
cpm	4	16	1.39
	5	18	1.56
	6	22	1.91
	7	24	2.08
	8.00 failure		

	Load (1000 lb)	Elongation (32nd inch)	Elongation (%)
#4	.5	3	.25
	1	6	.52
36"	2	10	.87
gage	3	15	1.30
2.5 cpm	4	19	1.65
	5	22	1.91
	6	25	2.17
	7	29	2.52
	8.65 failure		

#5

5/3 cpm 6.80 failure in the 208th cycle

#6

5/3 cpm 6.90 failure in the 158th cycle

COMMENTS - Test 3

1. Inspection of each splice in this test was made and results photographed. The cable failed near the tail of the upper splice in each sample. Snap back at failure severely distorts the cable in the region of the failure, but the other splice when examined yields good results. Appendix A discusses the failure mechanism of this splice when subjected to cyclic loading. This splice will be unacceptable for use in the field. However, a potted end fitting may be suitable.

TEST 4

Five cable samples were pulled to failure around a 90° sheave under a linearly increasing load that reached break strength in 10 minutes (Figure 4). After each sample was installed in the crosshead and around the sheave, it was preconditioned and marked with a gage length. Elongation measurements were taken in the region of the extension arm since a longer gage could be used. At slow loading rates the load was distributed around the sheave by cable slippage, so the elongation data should be reasonably accurate.

	Load (1000 lb)	Elongation (32nd inch)	Elongation (%)
#1	.5	7	.60
36 5/16"	1	9	.77
gage	2	14	1.21
	3	18	1.55
	4	22	1.89
	5	26	2.24
	6	31	2.67
	7	35	3.01
	8.43 failure		
#2	.5	2	.17
36"	1	4	.35
gage	2	9	.78
	3	13	1.13
	4	18	1.56
	5	22	1.91
	6	27	2.34
	7	32	2.78
	8.82 failure		
#3	.5	2	.17
36"	1	6	.52
gage	2	11	.95
	3	16	1.39
	4	20	1.74
	5	25	2.17
	6	30	2.60
	7	34	2.95
	8.70 failure		
#4	.5	2	.17
36"	1	4	.35
gage	2	10	.87
	3	14	1.22
	4	18	1.56
	5	22	1.91
	6	26	2.26
	7	30	2.60
	8	34	2.95
	8.44 failure		
#5	.5	2	.17
36"	1	5	.43
gage	2	10	.87
	3	15	1.30
	4	19	1.65
	5	24	2.08
	6	29	2.52
	7	34	2.95
	8.75 failure		

1K

STATISTICS - Test 4:

Maximum Failure Load:	8820 lb
Minimum Failure Load:	8430 lb
Average Ultimate Strength:	8628 lb
Average Elongation at Failure:	1.38 inch 3.83%

COMMENTS - Test 4

1. All failures occurred between the upper crosshead and the upper section of the sheave. Cable performance in this portion of the test was very similar to performance in Test 1 except for the noticeably higher break strengths.

2. Data 4a lists the regression data associated with the minimum and maximum failure loads for Test 4. Figure 4a plots this data, minimum failure load in red. Data 4b lists all data acquired in Test 4, which is plotted in Figure 4b as a nominal load-elongation curve for low rate tension loading around a 90° sheave to failure.

TEST 5

Five cable samples were pulled to failure around a 90° sheave at a loading rate that reached the rated break strength of the cable within one minute. No elongation data was taken due to the unpredictable binding and slippage of the cable around the sheave that would have invalidated results.

	Failure Load
#1	8480 lb
#2	8500 lb
#3	7000 lb
#4	8860 lb
#5	8750 lb

COMMENTS - Test 5

1..1. All but one failure occurred near the upper splice, as expected. Since the cable does not smoothly slip through the sheave, the upper section of cable should always be seeing more load than the cable in the extension arm below the sheave. Cable #2 failed in the lower end due to a faulty splice. One strand in the

eyelet had been snagged and pulled during splicing. It was assumed that the strand would adjust itself back into the proper weave when load was applied. However, when the cable squeezed together under load, this strand was immobilized and consequently carried more of the initial load than the other strands. It partially failed at 3000 lb load and completely failed at 5000 lb. Since this failure was in the eyelet, the main section of cable strength was not significantly degraded. It did illustrate, though, that if the cable is snagged during handling, the weave <u>must</u> be corrected before loading or the cable strength will be reduced by the strength of those strands that are snagged. This will be true even though the strands are not damaged.

2. There was no apparent reason for the low failure load in cable #3. I'm inclined to disregard this value.

TEST 6

Test 6 as defined in the initial test program is to be temporarily delayed until a suitable termination is developed, possibly a potted end fitting. Any further cyclic testing with the current splice will only continue to confirm the failure mechanism of that splice, not the performance of the main section of cable when loaded cyclically.

CREEP TEST

Appendix B shows the schematic of the creep tester that is being constructed to test SAMSON performance when subjected to a static load of 50-90 percent of its break strength over long periods of time. Design calculations are included to show how the tester was sized in regard to materials used. Phoßographs of the tester will be included in a subsequent report.

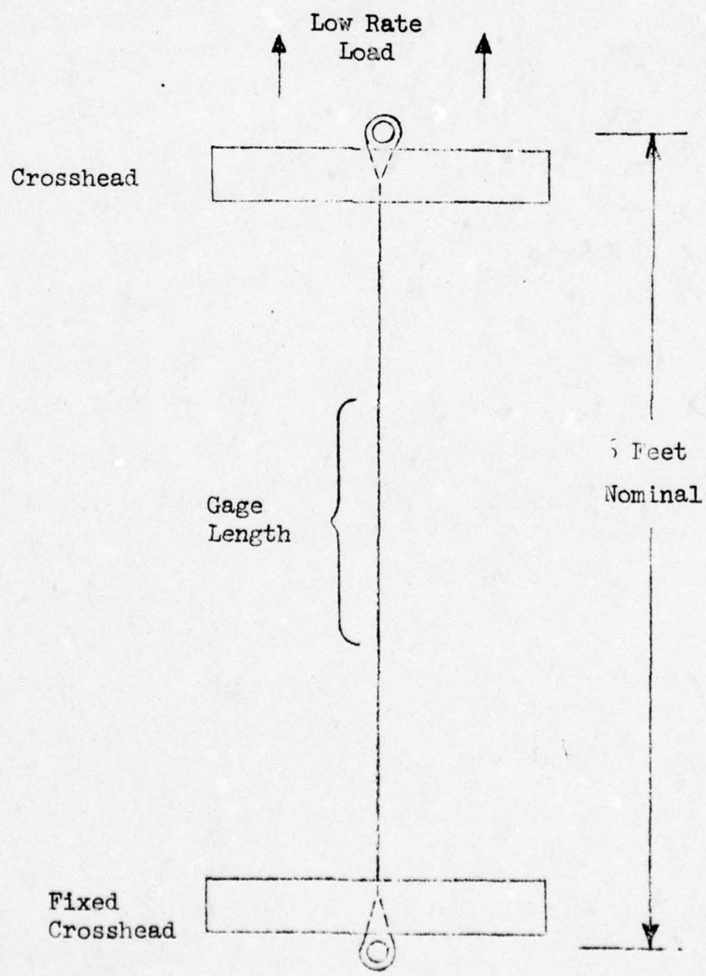

Low Rate
Load
Crosshead
Gage
Length
5 Feet
Nominal
Fixed
Crosshead

FIGURE 1

PROGRAM TEST #1 SAMSON

PT.NO.	X	Y
1	0.1375	1000.0000
2	0.0000	0.0000
3	0.3125	2000.0000
4	0.4375	3000.0000
5	0.5625	4000.0000
6	0.6875	5000.0000
7	0.7500	6000.0000
8	0.8750	7000.0000
9	0.9375	8000.0000

NO. POINTS = 9

X: MEAN= 0.527777778 ST.DEV.= 0.318858914
Y: MEAN= 4000 ST.DEV.= 2738.612788

CORR.COEFF.= 0.995073038

COEFFICIENTS

B(0)= -30.3685
B(1)= 5544.1458
B(2)= 2462.7319
B(3)= 693.6597

R SQUARE = 0.997941002

PT.NO.	X	Y
1	0.0000	0.0000
2	0.1875	1000.0000
3	0.3125	2000.0000
4	0.4375	3000.0000
5	0.5625	4000.0000
6	0.6563	5000.0000
7	0.7500	6000.0000
8	0.8750	7000.0000

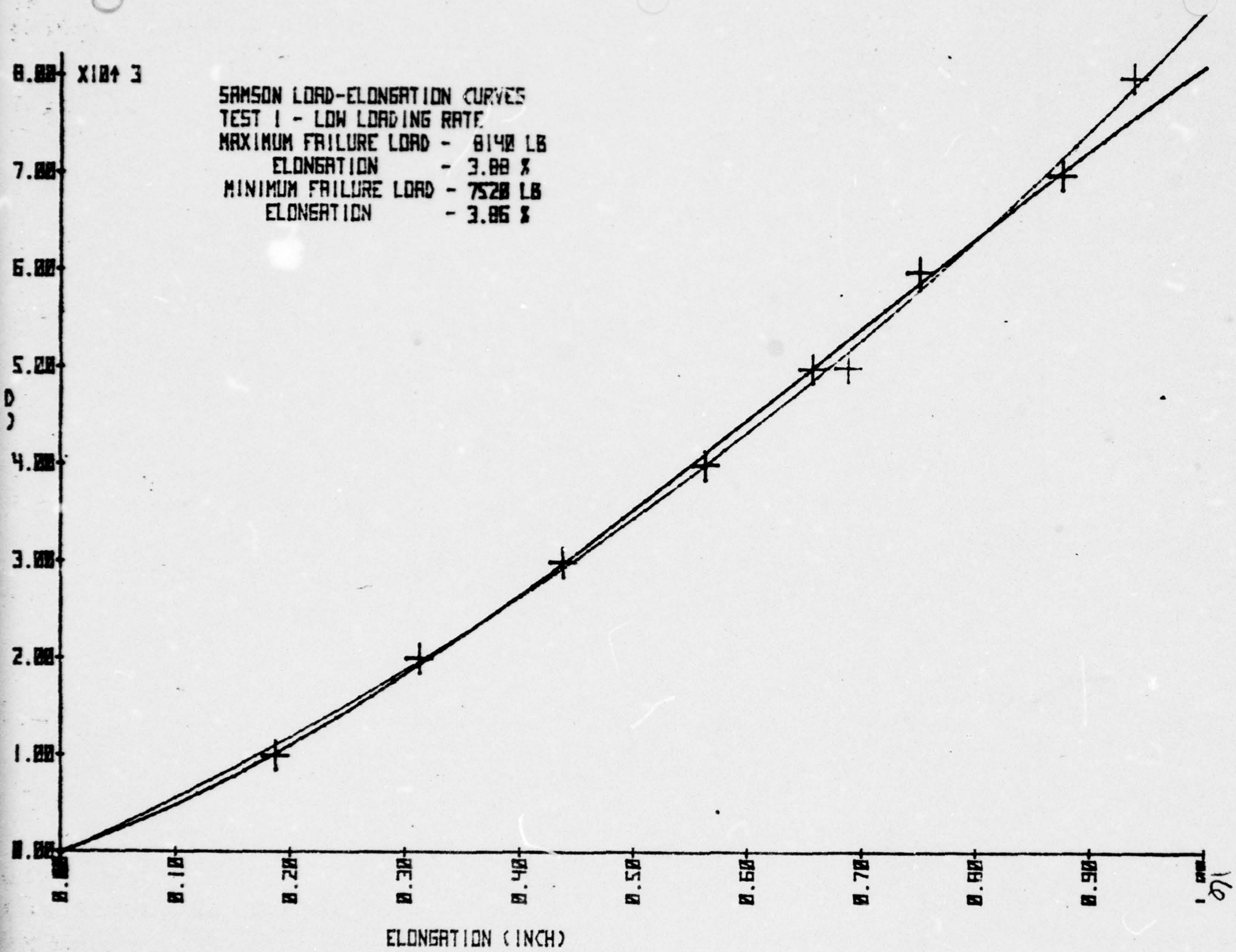
NO. POINTS = 8

X: MEAN= 0.47265625 ST.DEV.= 0.295727348
Y: MEAN= 3500 ST.DEV.= 2449.489743

CORR.COEFF.= 0.9955[illegible]797

COEFFICIENTS

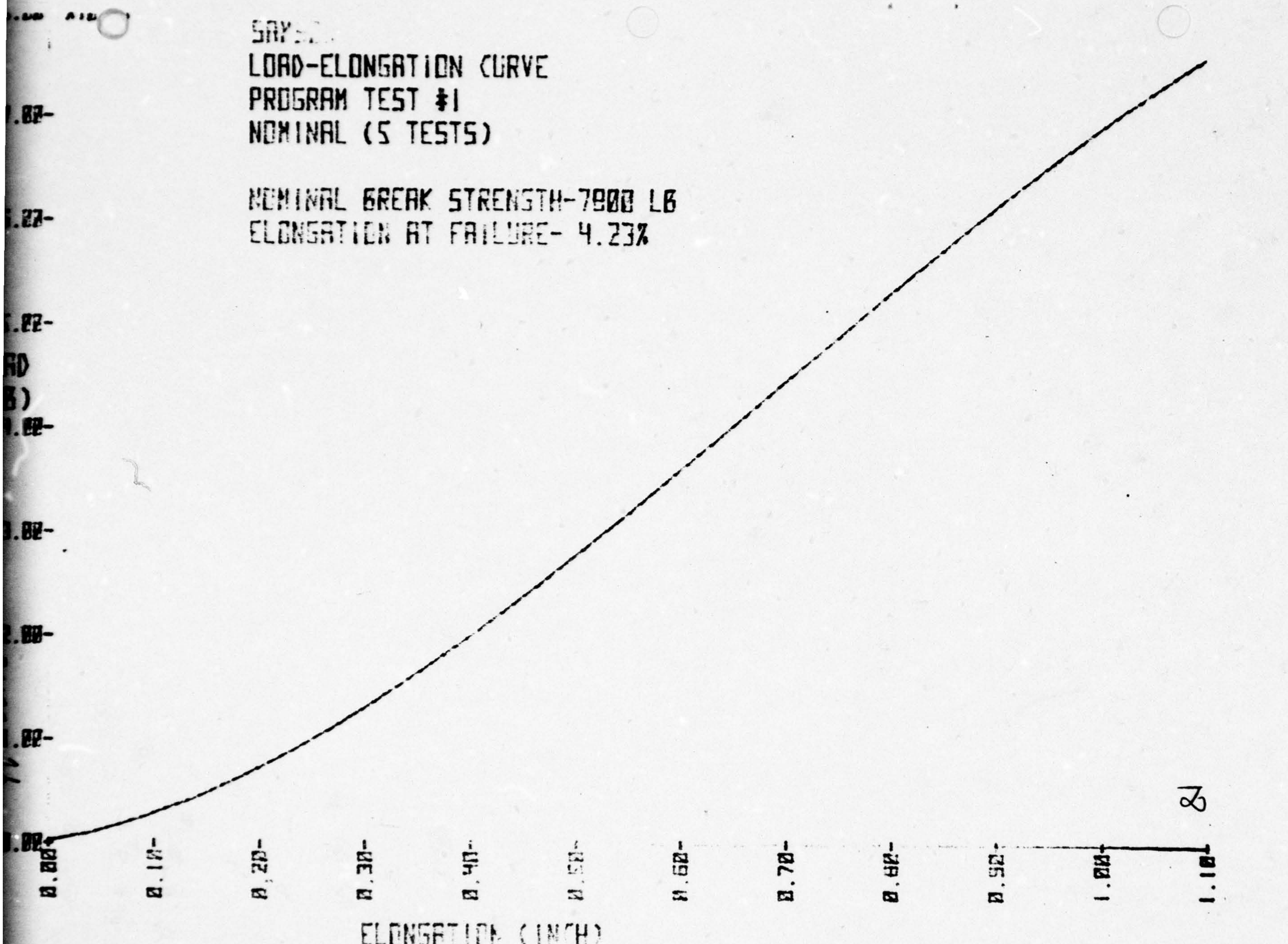
B(0)= 1.8179
B(1)= 1103.9360
B(2)= 7904.3887
B(3)= -3883.7361


X10↑ 3
SAMSON LOAD-ELONGATION CURVES
TEST 1 - LOW LOADING RATE
MAXIMUM FAILURE LOAD - 8140 LB
ELONGATION - 3.88 %
MINIMUM FAILURE LOAD - 7520 LB
ELONGATION - 3.86 %
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
ELONGATION (INCH)

16

1	0.0000	0.0000
2	0.0000	0.0000
3	0.0000	0.0000
4	0.0000	0.0000
5	0.0000	0.0000
6	0.1875	1000.0000
7	0.1875	1000.0000
8	0.3125	1000.0000
9	0.2500	1000.0000
10	0.2813	1000.0000
11	0.3125	2000.0000
12	0.3125	2000.0000
13	0.4375	2000.0000
14	0.3750	2000.0000
15	0.3438	2000.0000
16	0.4375	3000.0000
17	0.4375	3000.0000
18	0.5625	3000.0000
19	0.5313	3000.0000
20	0.4375	3000.0000
21	0.5625	4000.0000
22	0.5625	4000.0000
23	0.6563	4000.0000
24	0.5938	4000.0000
25	0.5625	4000.0000
26	0.[illegible]563	5000.0000
27	0.6875	5000.0000
28	0.7500	5000.0000
29	0.6875	5000.0000
30	0.6875	5000.0000
31	0.7500	6000.0000
32	0.7500	6000.0000
33	0.8438	6000.0000
34	0.8125	6000.0000
35	0.8125	6000.0000
36	0.8750	7000.0000
37	0.9375	7000.0000
38	0.9688	7000.0000
39	0.8750	7000.0000
40	0.8750	7000.0000

Date 16



SAY...
LOAD-ELONGATION CURVE
PROGRAM TEST #1
NOMINAL (5 TESTS)
NOMINAL BREAK STRENGTH-7900 LB
ELONGATION AT FAILURE- 4.23%
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
ELONGATION (INCH)

78

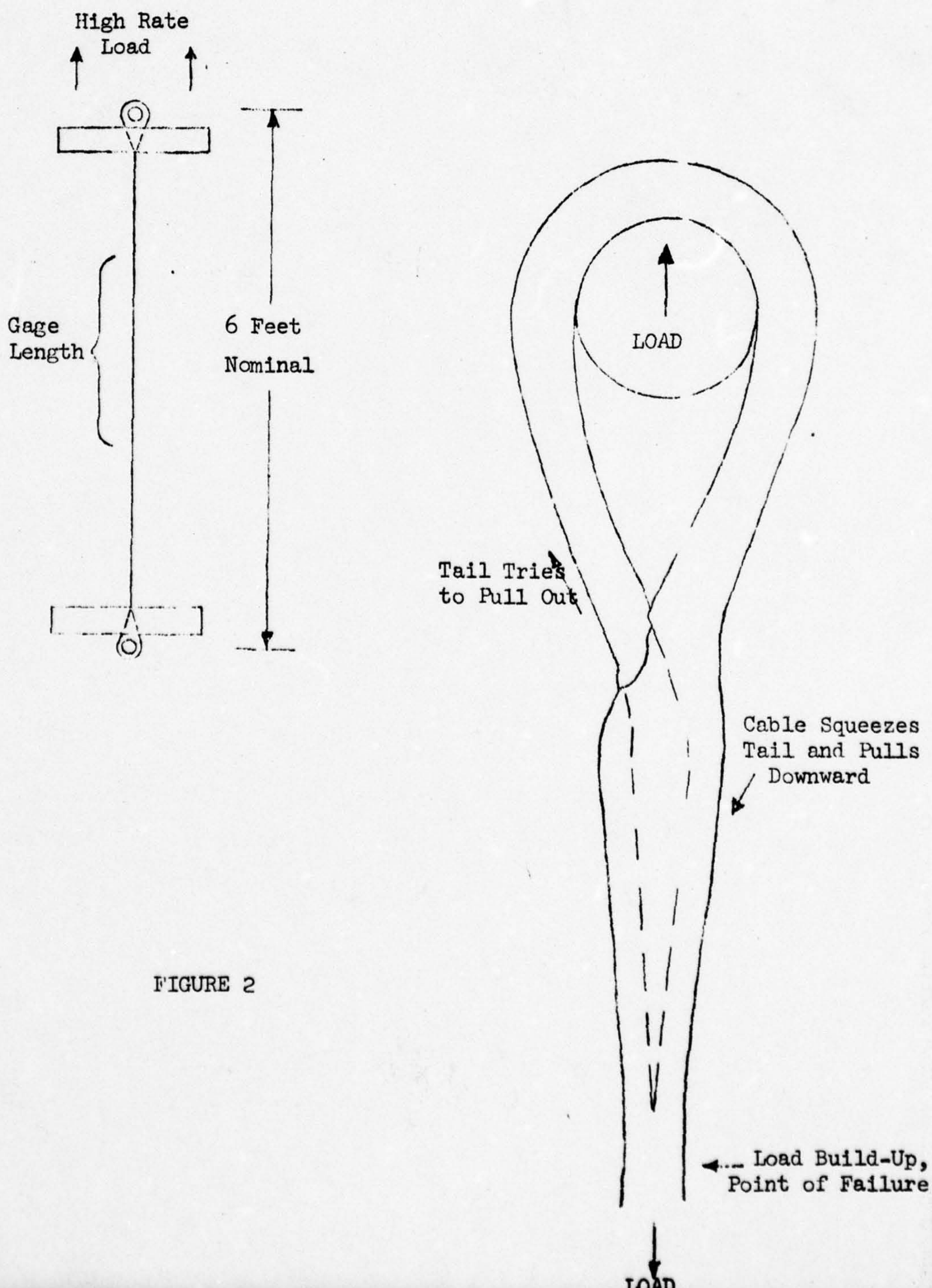

High Rate
Load
Gage
Length
6 Feet
Nominal
LOAD
Tail Tries
to Pull Out
Cable Squeezes
Tail and Pulls
Downward
Load Build-Up,
Point of Failure
LOAD

FIGURE 2

[redacted]

PROGRAM TEST #2 SAMSON

PT. NO.	X	Y
1	0.0000	0.0000
2	0.0313	500.0000
3	0.0625	1000.0000
4	0.1875	2000.0000
5	0.3125	3000.0000
6	0.4375	4000.0000
7	0.5625	5000.0000
8	0.6875	6000.0000
9	0.8125	7000.0000

NO. POINTS = 9

X: MEAN= 0.34375 ST.DEV.= 0.290923851
Y: MEAN= 3166.666667 ST.DEV.= 2500

CORR.COEFF.= 0.998372993

COEFFICIENTS

B(0)= 116.1[illegible]43
B(1)= 11324.0659
B(2)= -20[illegible].9[illegible]
B(3)= 544[illegible].6200

R SQUARE = 0.99[illegible]

PT. NO.	X	Y
1	0.0000	0.0000
2	0.3125	1000.0000
3	0.4375	2000.0000
4	0.5625	3000.0000
5	0.6875	4000.0000
6	0.8125	5000.0000
7	0.9375	6000.0000
8	[illegible]	7000.0000

NO. POINTS = 8

X: MEAN= 0.6[illegible] ST.DEV.= [illegible]
Y: MEAN= 3500 ST.DEV.= 2[illegible]

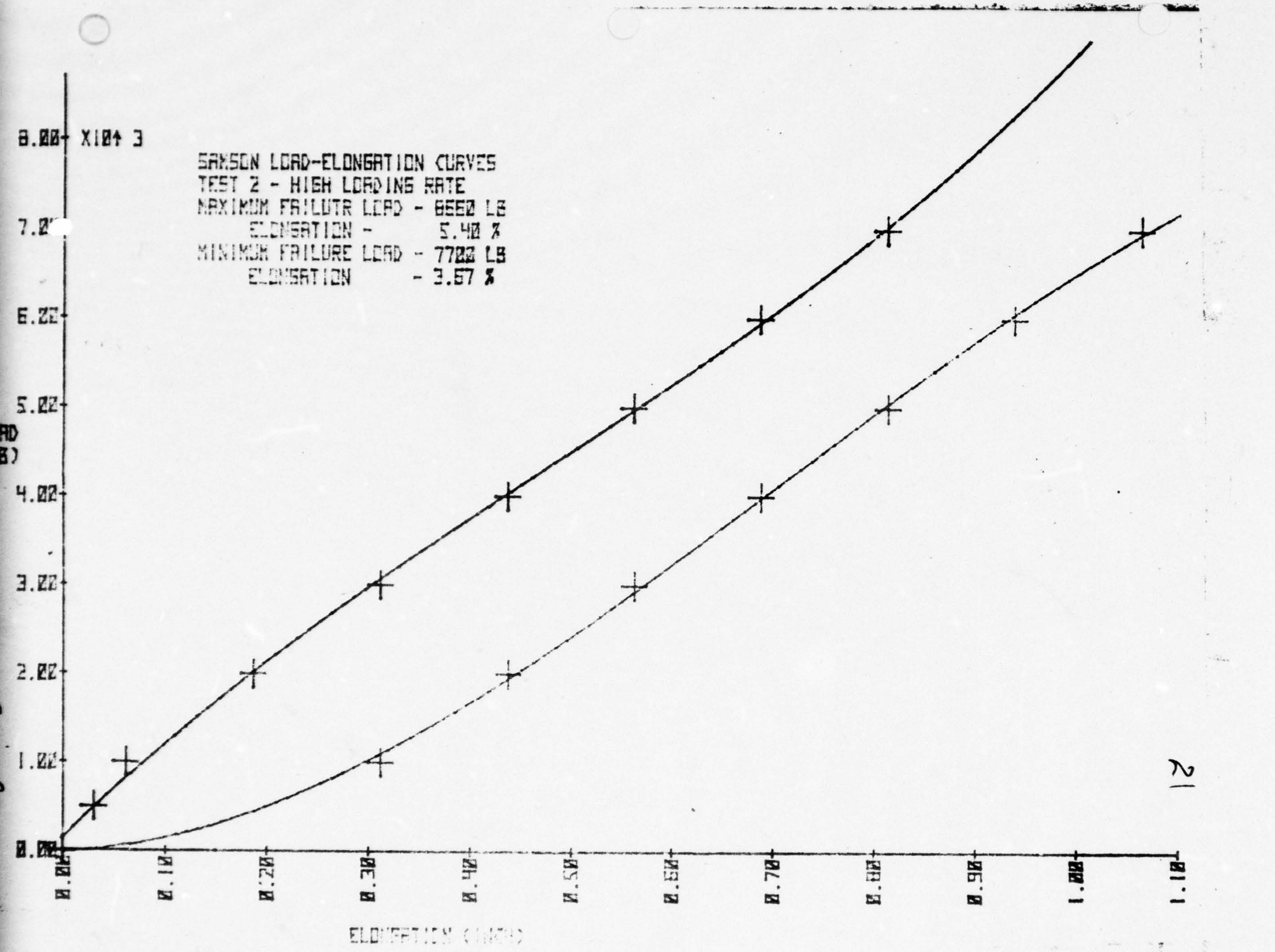
CORR.COEFF.= 0.[illegible]

COEFFICIENTS

B(0)= -1[illegible].41[illegible]
B(1)= 5[illegible].8[illegible]
B(2)= 11[illegible]5.9075
B(3)= -5278.8350

R SQUARE = 0.99[illegible]78017

Data 2a


X10↑ 3
SAMSON LOAD-ELONGATION CURVES
TEST 2 - HIGH LOADING RATE
MAXIMUM FAILUTR LOAD - 8550 LB
ELONGATION - 5.40 %
MINIMUM FAILURE LOAD - 7700 LB
ELONGATION - 3.67 %
8.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
LOAD (LB)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
ELONGATION

21

Figure 2a

22

PT.NO.	X	Y
1	0.0000	0.0000
2	0.0000	0.0000
3	0.0000	0.0000
4	0.0000	0.0000
5	0.0000	0.0000
6	0.1250	1000.0000
7	0.2500	2000.0000
8	0.3750	3000.0000
9	0.4688	4000.0000
10	0.6250	5000.0000
11	0.7500	6000.0000
12	0.0625	500.0000
13	0.1563	1000.0000
14	0.3125	2000.0000
15	0.4063	3000.0000
16	0.5313	4000.0000
17	0.6563	5000.0000
18	0.7500	6000.0000
19	0.9063	7000.0000
20	0.0313	500.0000
21	0.3125	1000.0000
22	0.4375	2000.0000
23	0.5625	3000.0000
24	0.6875	4000.0000
25	0.8125	5000.0000
26	0.9375	6000.0000
27	1.0625	7000.0000
28	0.0313	500.0000
29	0.0625	1000.0000
30	0.1875	2000.0000
31	0.3125	3000.0000
32	0.4375	4000.0000
33	0.5625	5000.0000
34	0.6875	6000.0000
35	0.8125	7000.0000
36	0.0313	500.0000
37	0.1250	1000.0000
38	0.2813	2000.0000
39	0.4063	3000.0000
40	0.5313	4000.0000
41	0.6250	5000.0000
42	0.7813	6000.0000
43	0.9063	7000.0000

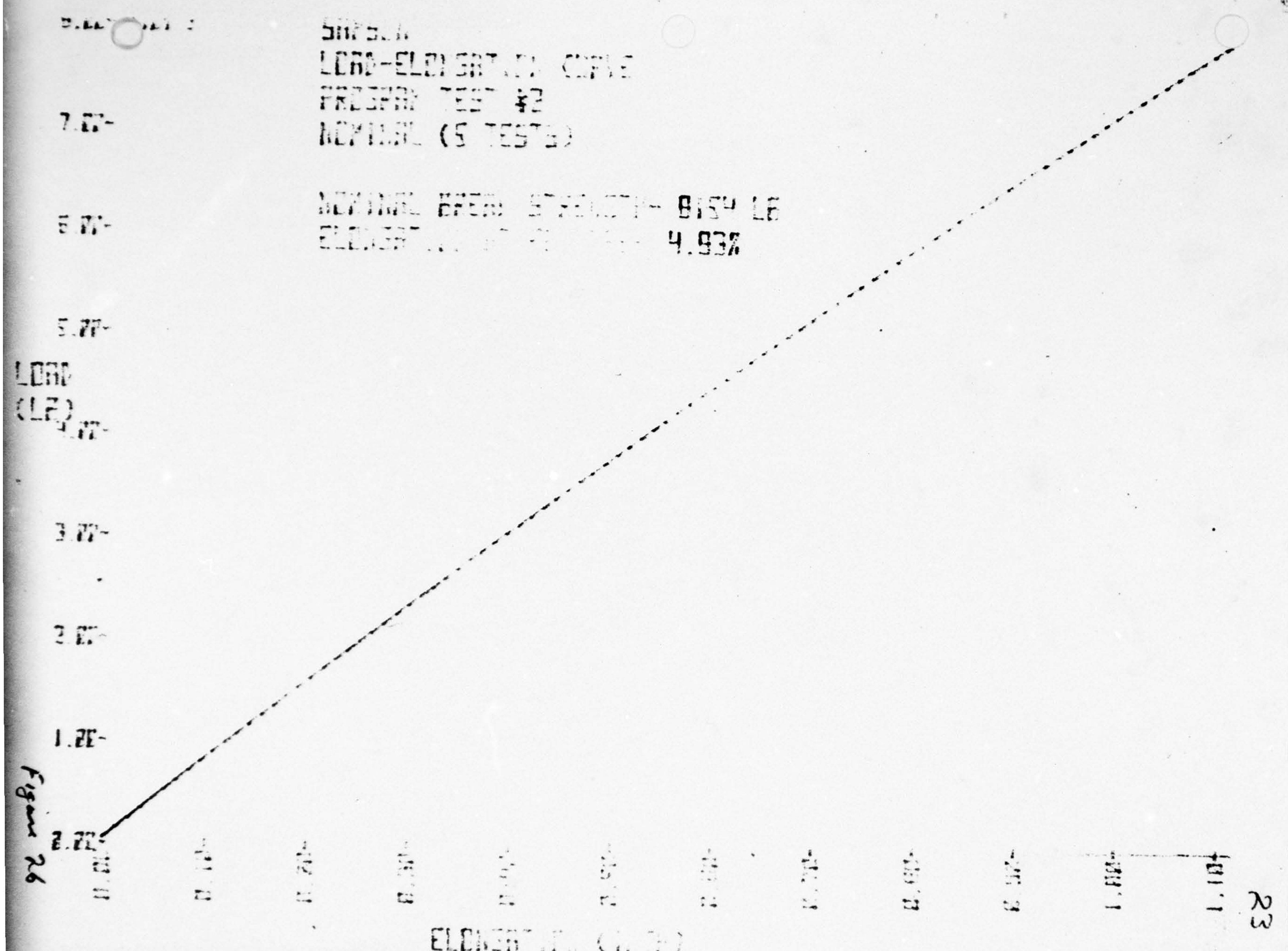


Figure 26

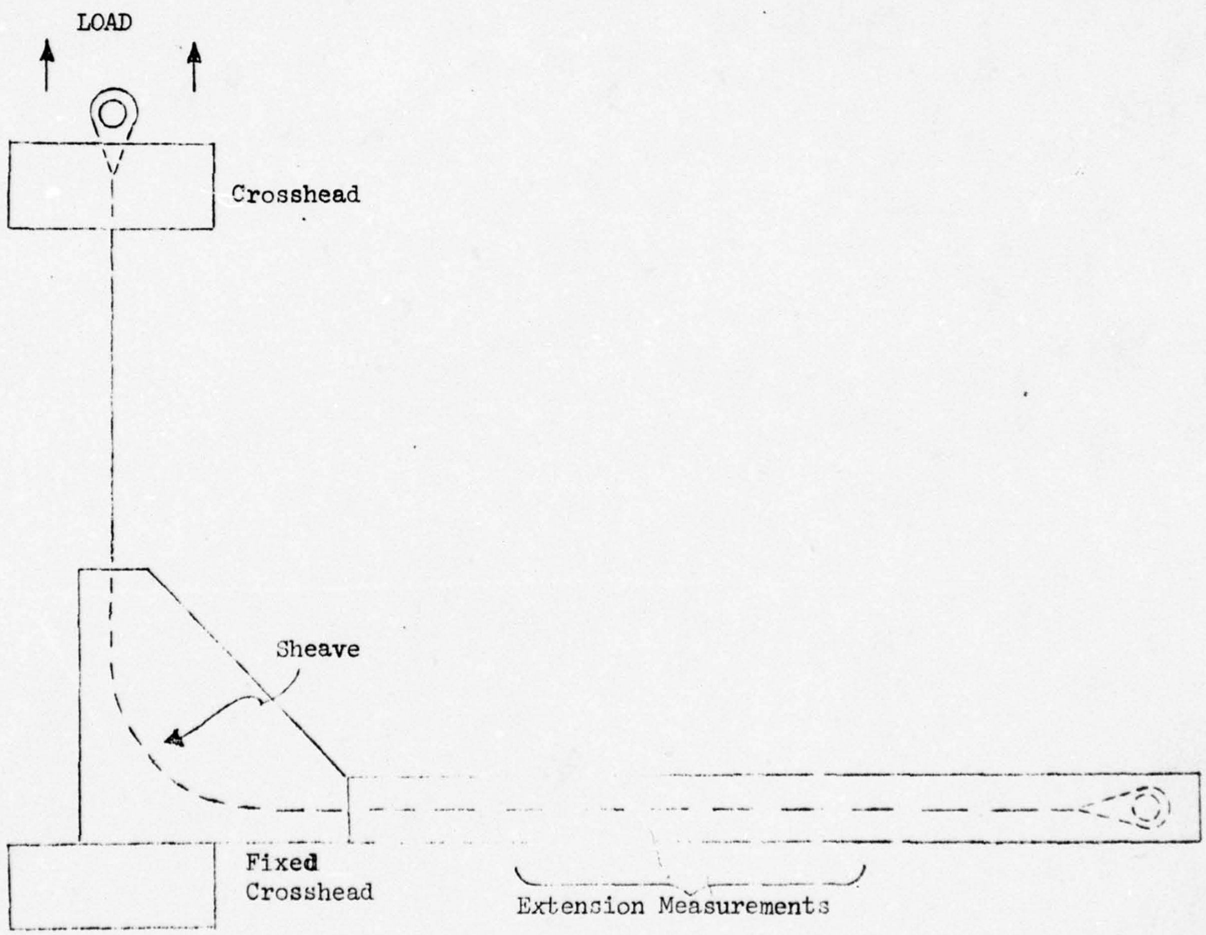

LOAD
Crosshead
Sheave
Fixed
Crosshead
Extension Measurements

FIGURE 4

PROGRAM TEST #4 SAMSON

PT.NO.	X	Y
1	0.0000	0.0000
2	0.0625	500.0000
3	0.1250	1000.0000
4	0.2313	2000.0000
5	0.4063	3000.0000
6	0.5625	4000.0000
7	0.5875	5000.0000
8	0.8438	[illegible]000.0000
9	1.0000	[illegible]000.0000

NO. POINTS = [illegible]

X: MEAN= 0.44097222 ST.DEV.= 0.35611443[illegible]
Y: MEAN= 3166.666667 ST.DEV.= 2500

CORR.COEFF.= 0.999649404

COEFFICIENTS

B(0)= 37.6587
B(1)= 7136.4901
B(2)= 350.[illegible]
B(3)= -522.5190

R SQUARE = 0.99[illegible]

PT.NO.	X	Y
1	0.0000	0.0000
2	0.2188	500.0000
3	0.2813	1000.0000
4	0.4375	2000.0000
5	0.5625	3000.0000
6	0.6875	4000.0000
7	0.8125	5000.0000
8	0.9688	6000.0000
9	1.0938	[illegible]000.0000

NO. POINTS = [illegible]

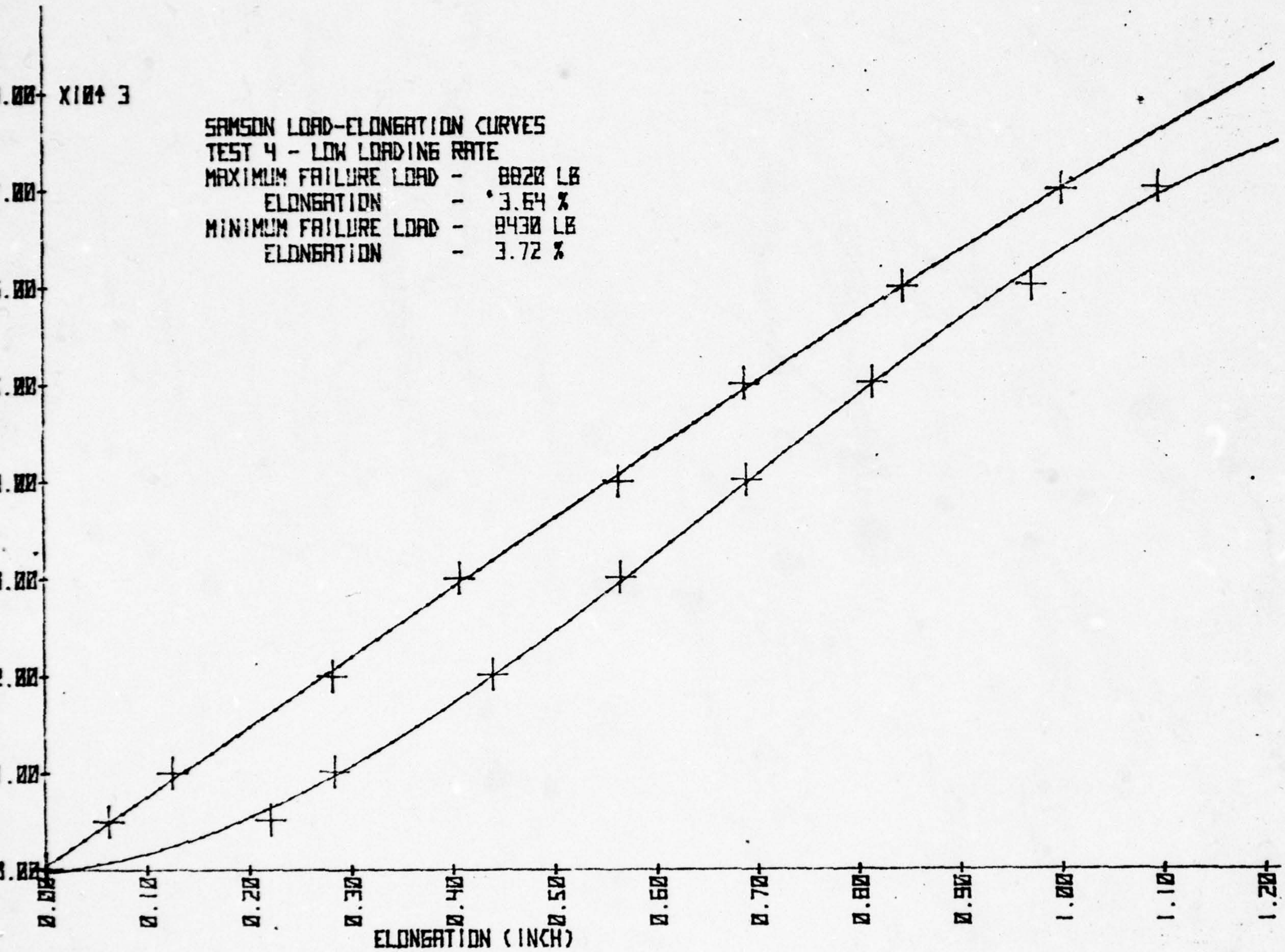
X: MEAN= 0.5625 ST.DEV.= 0.[illegible]
Y: MEAN= 3166.666667 ST.DEV.= [illegible]500

CORR.COEFF.= [illegible]

COEFFICIENTS

B(0)= -36.6119
B(1)= 924.2362
B(2)= 10779.8715
B(3)= -5311.1278

R SQUARE = 0.99998[illegible]



0.00 X10↑ 3
SAMSON LOAD-ELONGATION CURVES
TEST 4 - LOW LOADING RATE
MAXIMUM FAILURE LOAD - 8820 LB
ELONGATION - 3.64 %
MINIMUM FAILURE LOAD - 8430 LB
ELONGATION - 3.72 %
7.00
6.00
5.00
LOAD (LB)
4.00
3.00
2.00
1.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
ELONGATION (INCH)

Figure 4a

3	0.2813	1000.0000
4	0.4375	2000.0000
5	0.5625	3000.0000
6	0.6875	4000.0000
7	0.8125	5000.0000
8	0.9688	6000.0000
9	1.0938	7000.0000
10	0.0000	0.0000
11	0.0625	500.0000
12	0.1250	1000.0000
13	0.2813	2000.0000
14	0.4063	3000.0000
15	0.5625	4000.0000
16	0.6875	5000.0000
17	0.8438	6000.0000
18	1.0000	7000.0000
19	0.0000	0.0000
20	0.0625	500.0000
21	0.1875	1000.0000
22	0.3438	2000.0000
23	0.5000	3000.0000
24	0.6250	[illegible]000.0000
25	0.7813	[illegible]000.0000
26	0.9375	6000.0000
27	1.0625	7000.0000
28	0.0000	0.0000
29	[illegible]	500.0000
30	0.1[illegible]	1000.0000
31	[illegible]	2000.0000
32	0.4[illegible]	3000.0000
33	0.5625	4000.0000
34	0.[illegible]875	5000.0000
35	0.8125	6000.0000
36	0.9375	7000.0000
37	1.0625	8000.0000
38	0.0000	0.0000
39	0.0625	500.0000
40	0.1563	1000.0000
41	0.3125	2000.0000
42	0.4688	3000.0000
43	0.5938	4000.0000
44	0.7500	5000.0000
45	0.[illegible]063	6000.0000
46	1.[illegible]	7000.0000

NO. POINTS = 46

X: MEAN= 0.4[illegible] ST.DEV.= [illegible]
Y: MEAN= 3271.[illegible] ST.DEV.= [illegible]

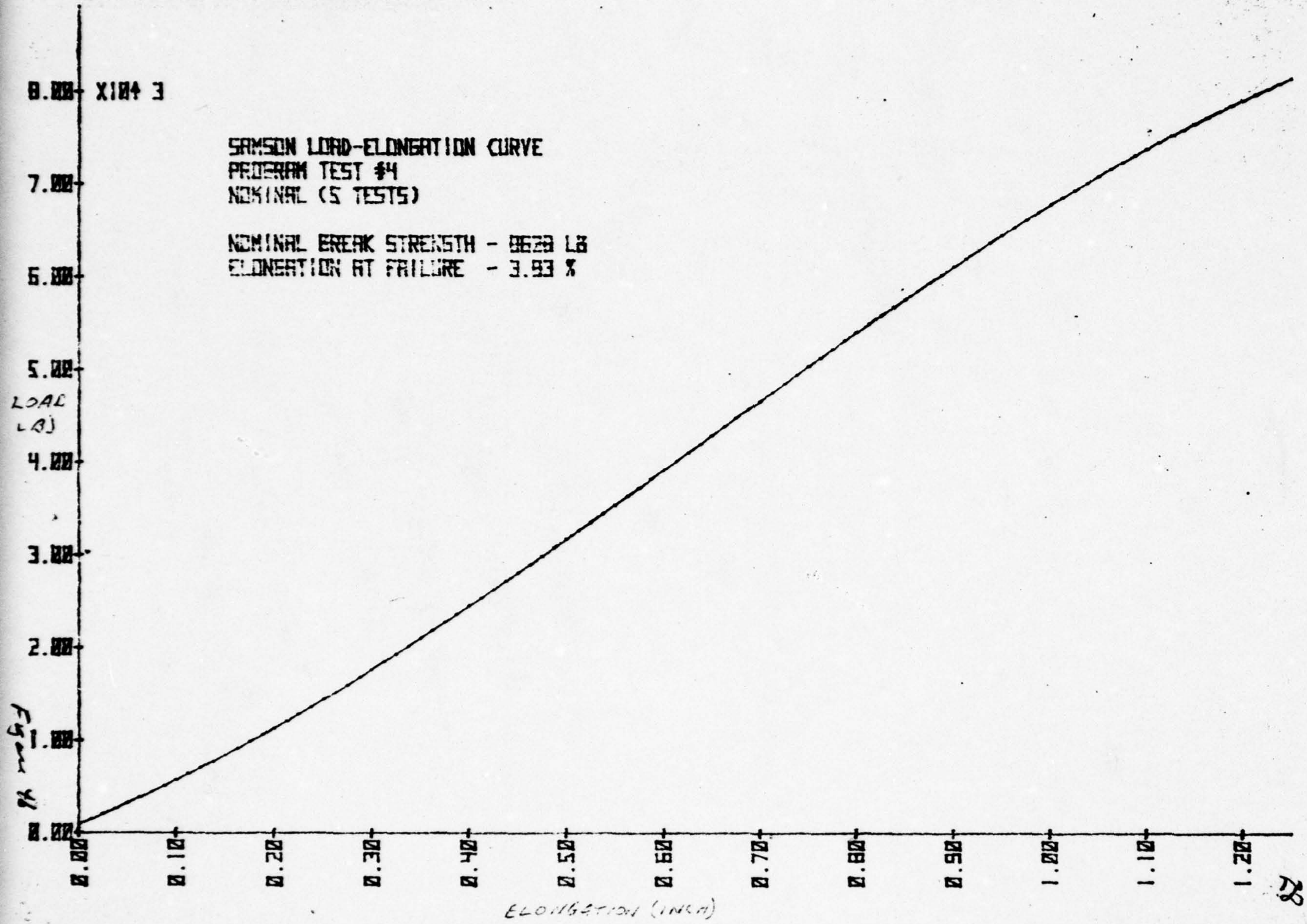
CORR.COEFF.= 0.98[illegible]

COEFFICIENTS

B(0)= [illegible]
B(1)= 427[illegible].1105
B(2)= 5126.1513
B(3)= -2715.5376

R SQUARE = 0.97[illegible]347647

Data 46


X10+ 3
SAMSON LOAD-ELONGATION CURVE
PROGRAM TEST #4
NOMINAL (5 TESTS)
NOMINAL BREAK STRENGTH - 8628 LB
ELONGATION AT FAILURE - 3.93 %
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
LOAD LB
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
ELONGATION (INCH)
Figure 4b

29

APPENDIX A

The "dead side tuck" splice is an eye splice which takes advantage of the unique construction of SAMSON braided cable to achieve a strength greater than the break strength of the cable itself. When unloaded, SAMSON cable can be compressed such that the helix angle becomes smaller and the cable diameter enlarges, creating a hollow circular cross section inside the cable. Another cable of similar dimension, not compressed, can then easily fit into the inside of the compressed cable. Once the load is placed on the first cable, its helix angle increases, it elongates, and its diameter decreases, thus squeezing tightly against the cable on the inside. The inside cable is held in place by this "squeezing", or normal force of the outside cable, and friction between the two cable surfaces. The greater the load on the outside cable, the greater the normal force. The longer the inside cable, the greater the contact surface.

The "dead side tuck" is an "outside" cable which is looped around a spindle to make an eyelet, then fed through its own weave to become an "inside" cable, as depicted in Figure A1. The tail or "inside" portion of the cable is depicted as tapered, which it must be to achieve full break strength in the cable. If the tail is blunt, a severe geometry change is caused, as depicted in Figure A2, and stress concentration causes a premature failure at this point. A tapered tail allows a smooth geometric transition, and thus any stress concentration is minimized. In a test of three cables with varying taper, it was discovered that a smoothly tapered splice allowed the cable to carry 8260 lb load prior to failure in the main section of the cable, whereas a tail blunted to 6 strands (the cable is constructed with 12 strands) failed at 7590 lb at the end of the tail (8% reduction in break strength). A splice with a 12 strand, blunt tail similarly failed at 6840 lb (over 17% reduction in break strength).

During static load, the tapered splice works well. During cyclic loading, however, there is a gradual strength reduction that leads to eventual failure at lower loads. The following text and figures describe this failure mechanism.

As the cable is loaded, the tail tries to pull out of the splice, but the squeezing action of the loaded cable immobilizes the tail. The outside cable carries most of the load and consequently elongates more than the tail. There is some relative motion between the outside cable and the tail, which causes some abrasion, but more importantly, most of this relative motion takes place near the end of the tail. As the load decreases during the cyclic loading, the end of the tail can be actually compressed until it hockles, which

leads to a drastic reduction in strength of the tail at that point. Continued loading and hockling causes failure through the tail at that point, and thus the tail has effectively been shortened and blunted. This action progresses up the tail until the tail has been blunted to the point that failure can occur at significantly lower loads.

Figure A3 shows results of Test #20, during which the cable was loaded 4000 ± 1000 lb for 500 cycles. Damage to the tail was minor. Subsequent loading to failure showed that the splice was still stronger than the cable (failure occurred away from the splice).

Figures A4-A6 show results of Tests #21 and #22, during which two cables were loaded 4000 ± 2000 lb for 500 cycles. Hockling in the tail is evident. Two strands in the tail had completely failed in Test #21. There was no reduction in break strength during the subsequent tensile test, but failure occurred in the splice in Test #21.

Figures A7 and A8 show results of Test #23, during which a cable was loaded 4000 ± 3000 lb (failure occurred in the 208th cycle at 6800 lb). Notice that the tail has been blunted to 6 strands, and that there has been some damage to the load carrying strands in the main section of the cable.

The above described mechanism is still taking place even at low load levels, so even though the number of cycles to failure may be much greater, splice failure will eventually occur even though the cable load has never approached its break strength. This splice seems to be unsatisfactory for dynamic loading conditions.

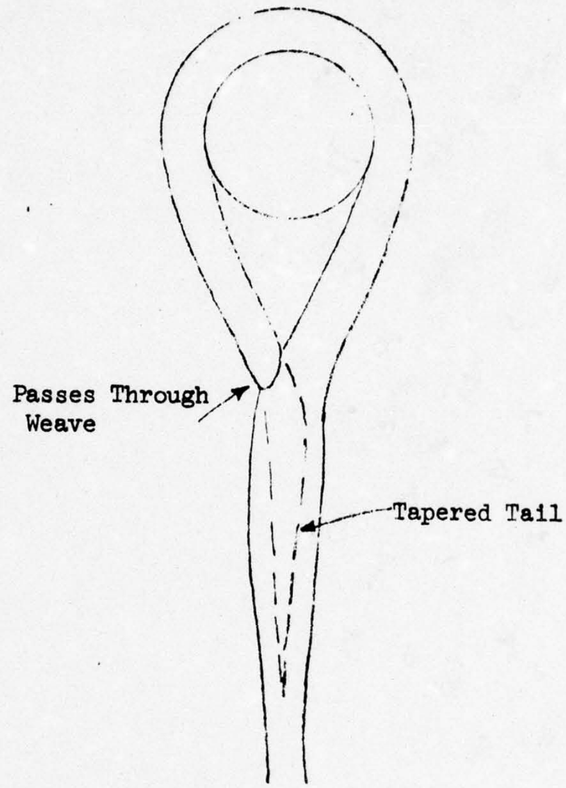
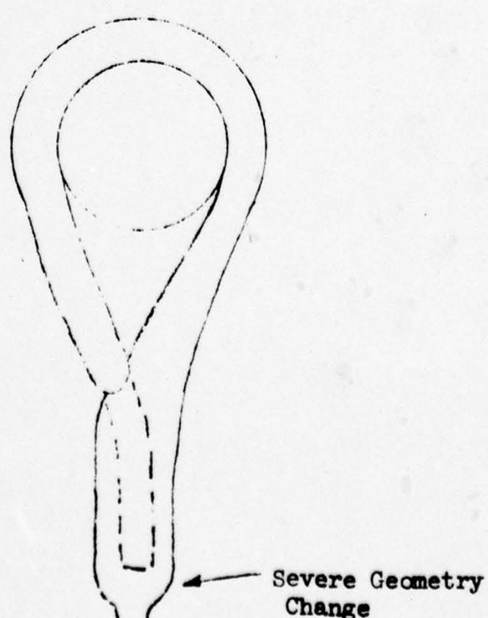


Figure A1

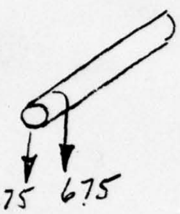


APPENDIX B

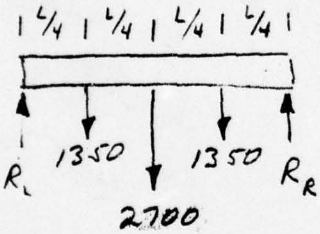
Break Strength 9000 lb

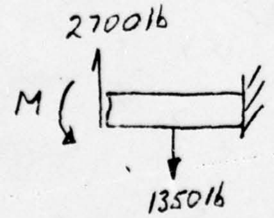
12 strands   750 lb/strand

90% of break = 675 lb



Worst case loading for 4 lines on a shaft



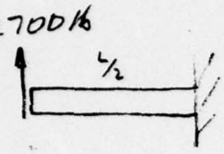


M must be sufficient to make slope of left end = 0.

θ & δ positive downward

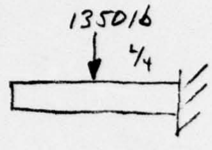
Solution assumes center of shaft fixed in a wall; i.e. $\theta = 0$

Beam deflection theory & superposition of simple solutions



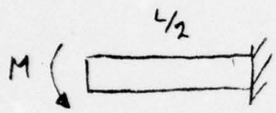
① $\theta = -\frac{2700\left(\frac{L}{2}\right)^2}{2EI} = -337.5\,\frac{L^2}{EI}$

② $\delta = \frac{-2700\left(\frac{L}{2}\right)^3}{3EI} = -112.5\,\frac{L^3}{EI}$



③ $\theta = \frac{1350\left(\frac{L}{4}\right)^2}{2EI} = 42.1875\,\frac{L^2}{EI}$

④ $\delta = \frac{1350\left(\frac{L}{4}\right)^2}{6EI}\left[3\left(\frac{L}{2}\right) - \frac{L}{4}\right] = 17.578\,\frac{L^3}{EI}$



⑤ $\theta = \frac{M\left(\frac{L}{2}\right)}{EI} = +295.3\,\frac{L^2}{EI}$ for $\theta = 0$ at end adding ① & ③

⑥ $\delta = \frac{M\left(\frac{L}{2}\right)^2}{2EI}$

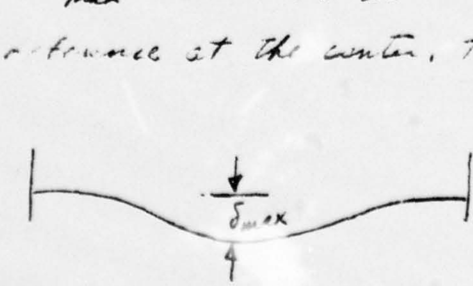
Solving for M in ⑤

$M = 590.625\,L$

⑥ $\delta = \frac{(590.625L)\left(\frac{L}{2}\right)^2}{2EI} = 73.828\,\frac{L^3}{EI}$

$\delta_{TOTAL} = (-112.5 + 17.578 + 73.828)\,\frac{L^3}{EI} = -21.1\,\frac{L^3}{EI}$

where δ_{max} occurs at the left end of cantilever with zero reference at the center. Therefore for the original system



δ_{max} $21.1\,\frac{L^3}{EI}$

For a solid steel, 7/8" dia circular shaft

$E = 30 \times 10^6$ psi

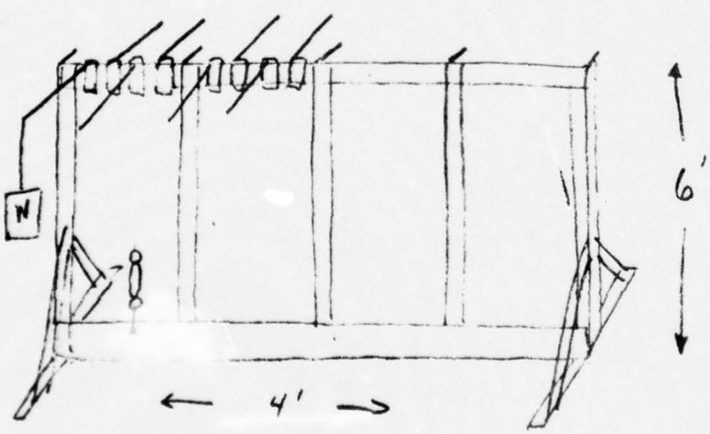
$I = \frac{\pi r^4}{4} = .0288 \text{ in}^4$

$\delta_{max} = \frac{21.1 L^3}{8.632 \times 10^5}$

for $L = 12"$

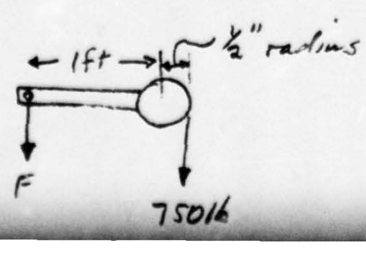
$\delta_{max} = .042$ inch

* 7/8" solid shaft should be adequate to support 4 lines.



For a 3 foot sample, at an elongation of 1%, system must be capable of adjusting for .36 inch - can easily be compensated for by a turnbuckle.

End view of load -

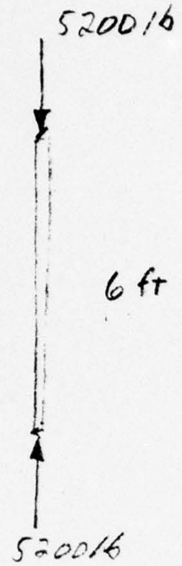


$750(\frac{1}{2}) = 12F$

$F = 31.25 lb$

easily achievable by dead wts.

Max load in supports



Safety factor of 2 in yield

$\sigma = \frac{P}{A} = \frac{5200}{A} = \frac{35,000}{2}$ for .2% C hot rolled steel

$A = .297 \text{ in}^2$

Buckling - assuming pivoted both ends

$P_{cr} = \frac{\pi^2 EI}{l^2} = \frac{\pi^2 EA^2}{(\frac{l}{r})^2}$

$l = 72''$

* for $3 \times 1\frac{1}{2}$ channel 4.1 lb/ft

$\left(\frac{l}{r}\right)^2 = \left(\frac{72}{.41}\right)^2 = 30839$

$P_{cr} = \frac{\pi^2 (30 \times 10^6)(1.19)^2}{30839} = 13,596 \text{ lb}$

Can go to a smaller channel

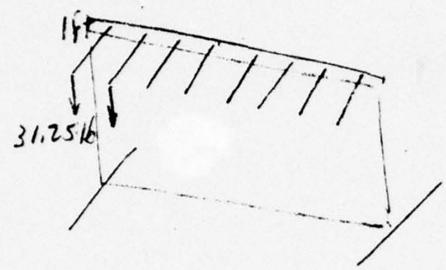
For above channel

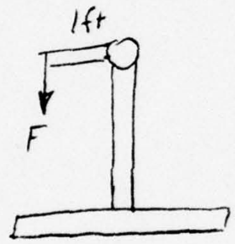
S.F. = 2.6 in buckling

Pcr will actually be higher since base is not free to pivot

* Set supports in $3\frac{1}{2} \times 3\frac{1}{2}$ angle $\frac{1}{4}$ thick

Tipping: assume full weights on one side only





$F_{equiv} = 250$ lb

or $T = 250$ ft lb

+ F thru centerline

Structure weight:

W_1: 5 $3 \times 1\frac{1}{2}$ channels 6 ft long 4.1 lb/ft

$W_1 = 123$ lb

W_2: 7/8 dia shaft 4 ft long 2.07 lb/ft

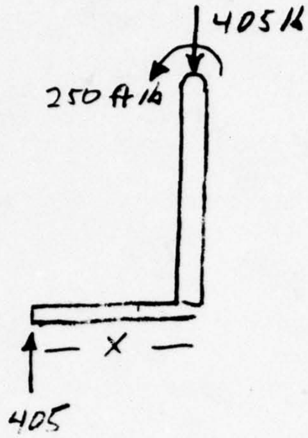
$W_2 = 8.3$ lb

W_3: Angle base $3\frac{1}{2} \times 3\frac{1}{2}$ $\frac{1}{4}$ 4 ft long 5.8 lb/ft

$W_3 = 23.2$ lb

$W_{TOT} > 405$ lb

At Tipping

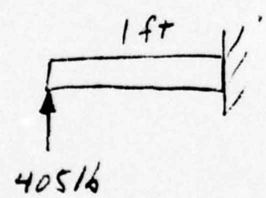


$405x = 250\text{ ft lb}$

$x = .618\text{ ft}$ for 1 leg - 2 legs actually carrying the 405 lb load.

* 1 foot legs should be sufficient to prevent Tipping in the most extreme case.

Bending of Leg $3\frac{1}{2} \times 3\frac{1}{2}$ angle



$$\delta = \frac{405(12)^3}{3(30\times10^6)(2)} = .004\text{ inch}$$

* Minimal bracing required
Can use $1\frac{1}{2}\times1\frac{1}{2}\times\frac{1}{4}$ for leg with same for brace at 6" out leg, 45° inclination

Friction:

Smooth steel shaft 7/8" OD

Hollow pipe 1" OD 2 inches wide

Effective contact area over 1/4 circumference

$A = \frac{\pi}{4}\left(\frac{7}{8}\right)(2) = 1.37\ in^2$

$N = 1350\ lb$

$F = \mu N < 13.5\ lb$ to keep error within 2%

$\mu < .01$

Possibly can be achieved with grease only

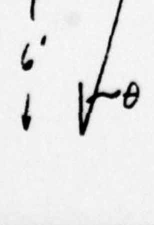
If not, needle bearings required

Load Pipe Displacement on 7/8" OD shaft assuming no friction, i.e. shaft to pipe force must be normal to contact surface

If shaft deflects .042 inch at center (6")

Slope of shaft (assuming pivoted ends) is

$\tan\theta = \frac{.042}{6"} = 7 \times 10^{-3}$



Lateral displacement of Load pipe would be

$72 \tan\theta = .5\ inch$

STUDY OF BASIC STRENGTH CHARACTERISTICS

OF

PHILLYSTRAN (IMPREGNATED KEVLAR 29) CABLE
PS29-C.25J
0.25 inch diameter (nominal)

33 pounds/1000 feet
(with polyurethane jacket)

20 January 1975

OBJECTIVE

To establish the basic strength characteristics of Phillystran when subjected to a tensile load which is steadily increased to failure within a prescribed time.

EQUIPMENT

Tinius-Olsen 120,000 Super L Tensile Test Machine
10 foot steel tape measure graduated in 1/32 inch increments
Nicopress sleeves and crimping tool

PROCEDURE

Five tests were planned (as described in the initial test program) to evaluate the basic strength properties of Phillystran. Only one test was conducted to completion, due to unexpected results in the first test series. Additional tests were devised to explain these results. The tests are defined below, with comments on the results. The following information applies to all of the tests:

1. All end terminations were made using four (4) Nicopress sleeves #18-10-F6 crimped with Nicopress hand tool #3-F6-950 (See Fig 2a and 2b). Philadelphia Resins Corp. states that full cable strength will be obtained when four sleeves are used.

2. Elongation measurements were taken over a 72 inch (nominal) gage length, with a steel rule graduated in 1/32 inch increments. Elongation measurements were discontinued at 5000 lb load due to possible cable failure prior to reaching 6000 lb.

3. All data plots were performed on an HP-9830 computer using polynomial regression to achieve a least-squares fit. In all cases a third degree polynomial was selected. Break strength was recorded directly from the testing machine and is therefore as accurate as the machine calibration. However, per cent elongation at failure, extracted from the upper region of the data plot above 5000 lb, is only as accurate as the fit of the polynomial. It should therefore be used only as an approximation.

4. Ambient room temperature was $70^{\circ} \pm 5^{\circ}$ F.

5. The polyurethane jacket was left on the sample except in the area of the end terminations.

6. Preconditioning consisted of cycling the cable 10 times from 0 to 3000 lb load.

TEST 1

Five cable samples were pulled to failure under a linearly increasing load that reached rated break strength in 10 minutes. After each sample was installed in the crosshead, a gage length was marked on the cable and the steel rule was attached. Elongation data in the zero load row indicates elongation due to work stretching during the preconditioning phase. Gage length is the initial length of cable during testing after preconditioning.

	Load (1000 lb)	Elongation (1/32nd inch)	Elongation (%)
#1	0	(29)	(1.26)
72 29/32"	.5	9	.39
gage	1	16	.69
	2	27	1.16
	3	38	1.63
	4	49	2.10
	5	58	2.49
	5.52 failure in splice		
#2	0	(20)	(.87)
72 13/32"	.5	8	.35
gage	1	16	.69
	2	27	1.16
	3	38	1.64
	4	44	1.90
	5	63	2.72
	5.44 failure in splice		
#3	0		
72"	.5	12	.52
gage	1	20	.87
	2	33	1.43
	3	44	1.91
	4	55	2.39
	5	66	2.86
	6.59 failure 16" away from splice		
#4	0	(20)	(.88)
71 20/32"	.5	11	.48
gage	1	19	.83
	2	32	1.40
	3	43	1.88
	4	55	2.40
	5	68	2.97
	5.63 failure 5" away from splice		

	Load (1000 lb)	Elongation (1/32nd inch	Elongation (%)
#5	0	(16)	(.73)
72"	.5	12	.52
gage	1	21	.91
	2	34	1.48
	3	52	2.26
	4	58	2.52
	5	71	3.08
	5.85 failure 3" away from splice		

Statistics - Test 1

Maximum Failure Load: 6590 lb

Minimum Failure Load: 5630 lb

Average Break Strength: 6110 lb

Average Elongation at Failure 2.65 inch
3.68 %

Comments - Test 1

1. Since failure occurred in the splice in samples #1 and #2, statistics do not include the data from these samples. However, load-elongation data from these two samples up to 5000 lb load should still be valid, so data from samples #1 and #2 were used in plotting the nominal load-elongation curve.

2. Average break strength is based on the average of the maximum and the minimum failure loads listed in the statistics.

3. Failure generally occurs abruptly in three or less strands, then progresses one strand at a time through the remaining strands if loading is continued.

4. Mild snapping can be heard intermittently above a load of 4200 lb. Momentary load drop-off, accompanying most snaps above 5000 lb, indicates an abrupt change in length of the sample. The snapping is therefore most likely caused by partial failure of the cable occurring at loads somewhat less than ultimate strength. For example, sample #3 snapped at 4240, 4660, 4820, and 5240 lb. Load dropped off momentarily at 5800 and 6000 lb.

5. Data 1a lists the polynomial regression data for the minimum and maximum failure loads for Test 1. Figure 1a plots this data, with the curve associated with the minimum failure load in red. Data 1b lists all the data points acquired during Test 1, which is used to plot Figure 1b, a nominal load-elongation curve for low rate straight tension loading to failure.

TEST 2

One cable sample was pulled to failure under a linearly increasing load that reached rated break strength within one minute. Test procedure was the same as in Test 1. Preconditioning was accomplished and elongation during preconditioning is listed in the zero load row.

	Load (1000 lb)	Elongation (1/32 inch)	Elongation (%)
#1	0	(23)	(1.0)
72 23/32"	1	25	1.07
gage	1.5	30	1.29
	2	36	1.55
	2.5	46	1.98
	3	57	2.45
	3.5	62	2.66
	4	67	2.88
	4.5	77	3.31
	5	83	3.57
	5.95 failure near splice		

Comments - Test 2

1. Testing was discontinued because it appeared that the splice was causing premature failure. A different splice was tried to see how much strength reduction was being caused by the Nicopress splice.

I used splicing instructions from WIRECO Brown Strand Wire Rope manual (Figure 3) to make a loop splice in a Phillystran sample. Upon loading, the sample failed at 5150 lb in the splice. WIRECO claims 90% efficiency for 1/4" diameter wire rope using this splice. However, since Kevlar stretches less and is therefore less accommodating to the change of geometry in the splice, I would not rely too heavily on this figure. WIRECO claims 80% efficiency for 7/8" diameter and up. Using this figure:

$$P_{ult} = \frac{5150}{.8} = 6437 \text{ lb}$$

This failure load compares well with Test 1, sample #3 results.

Comments - Additional Testing

1. Since Kevlar 29 exhibits little if any plastic flow, I seriously question the efficiency of construction of Phillystran. The 7x7 construction causes the center strand to be shorter than the outer six strands for a given length of cable. If

all strands exhibit the same load-elongation properties, then the center strand must carry more load than the outside strands. (See Appendix A)

TEST 3

I ran three additional tests according to test procedure listed for Test 1. In two of these tests I cut the center strand to see what effect this would have on the break strength of the sample. For the third test, I cut one outer strand.

#1 Center Strand Cut
First snap heard at 5060 lb, first load drop back at 5500 lb. Failure occurred at 5930 lb in three strands.

#2 One Outer Strand Cut
Mild snaps at 3500, 3600 and 4260 lb. Load dropped back at 4360 lb. Failure occurred at 5140 lb.

#3 Center Strand Cut
Mild snaps at 4860 and 4920 lb. Cable was inspected, revealing kinking in the center filaments of the outer strands. (Each strand is made up by twisting six filaments around a center core filament similar to the six strands twisted about the center core strand.) The kinking is not a complete failure but is a weak point in the filament. Subsequent loading and inspection revealed damage either from abrasion or individual fiber failure (whiskers or fuzziness along the filaments). The sample failed at 5880 lb at the point where the center strand had been cut. Subsequent inspection revealed that:

a. The center strand had failed 43" up from the point where the center strand had been cut. (See Figure 4a) This would indicate that the center strand was being constrained by the outer strands so that it picked up load again a short distance away from the cut.

b. The center filament of the center strand had failed all along itsslength, leaving no piece longer than 5 1/2 inches maximum. (See Figure 4b)

c. Two outer strands had center filament failures at points away from the actual point of cable failure. (See Figure 5a and 5b)

Comments - Test 3

1. It appears that the center strand is the first to fail and that it fails at a low enough load so that it contributes nothing toward break strength.

2. Tests of single strands of Phillystran indicate a nominal break strength of 1000 lb per strand. If this entire value were added to the results of tests #1 and #3 (break strength for six outer strands) the maximum achievable break strength would be 6930 lb, still short of Philadelphia Resins guaranteed minimum break strength of 7000 lb.

CONCLUSIONS

1. Phillystran is not acceptable in its present form. The construction is not optimum for the type of material.

2. Strength to weight could possibly be improved by eliminating the center strand. Phillystran without jacket weighs 21 lb per 1000 feet. Eliminating the center strand would reduce this weight to 18 lb per 1000 feet, which compares favorably with unjacketed SAMSON (18.5 lb per 1000 feet). However, six strands of Phillystran will break at about 5900 lb, while SAMSON has an average break strength of 7800 lb. It appears that Phillystran's resin impregnation adds weight without adding strength to the cable.

1	0.0000	0.0000
2	0.3750	500.0000
3	0.6250	1000.0000
4	1.0313	2000.0000
5	1.3750	3000.0000
6	1.7188	4000.0000
7	2.0625	5000.0000

Data associated with 6590 lb failure load

NO. POINTS = 7

X: MEAN= 1.0268 ST.DEV.= 0.743124788
Y: MEAN= 2214.285714 ST.DEV.= 1867.644302

CORR.COEFF.= 0.993400469

COEFFICIENTS

B(0)= 0.1852
B(1)= 872.3622
B(2)= 1332.4545
B(3)= -281.9281

R SQUARE = 0.999986118

PT.NO.	X	Y
1	0.0000	0.0000
2	0.3438	500.0000
3	0.5938	1000.0000
4	1.0000	2000.0000
5	1.3438	3000.0000
6	1.7188	4000.0000
7	2.1250	5000.0000

Data associated with 5630 lb failure load.

NO. POINTS = 7

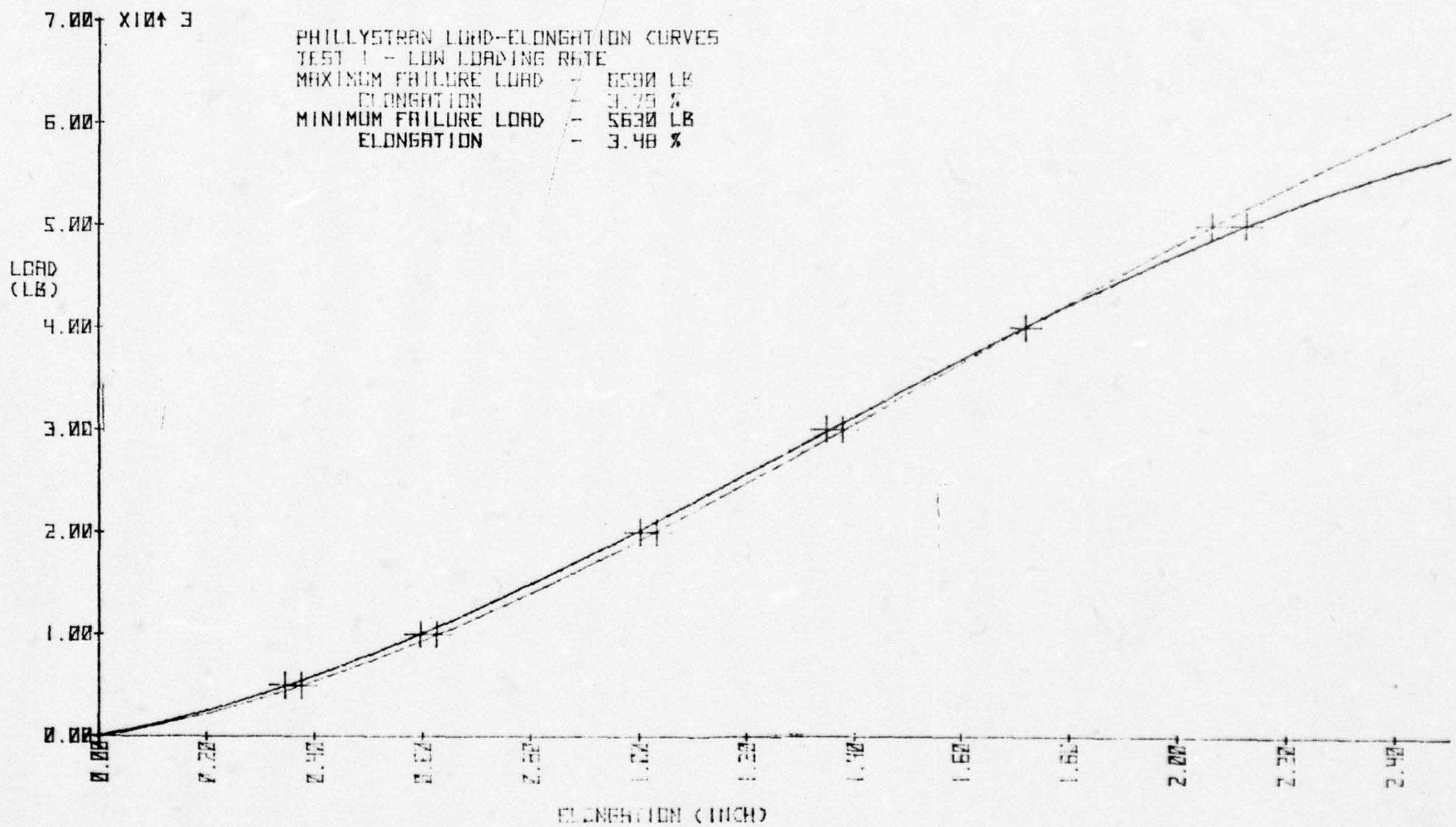
X: MEAN= 1.017885714 ST.DEV.= 0.763091789
Y: MEAN= 2214.285714 ST.DEV.= 1867.644302

CORR.COEFF.= 0.996370906

COEFFICIENTS

B(0)= 3.3295
B(1)= 982.9287
B(2)= 1380.8711
B(3)= -346.9396

R SQUARE = 0.999942219



7.00
X10↑ 3
6.00
5.00
4.00
3.00
2.00
1.00
0.00
LOAD
(LB)
PHILLYSTRAN LOAD-ELONGATION CURVES
TEST 1 - LOW LOADING RATE
MAXIMUM FAILURE LOAD - 6590 LB
ELONGATION
MINIMUM FAILURE LOAD - 5630 LB
ELONGATION - 3.48 %
0.00
2.00
ELONGATION (INCH)

Figure 1a

PT.NO.	X	Y
1	0.0000	0.0000
2	0.2813	500.0000
3	0.5000	1000.0000
4	0.8438	2000.0000
5	1.1875	3000.0000
6	1.5313	4000.0000
7	1.8125	5000.0000
8	0.0000	0.0000
9	0.2500	500.0000
10	0.5000	1000.0000
11	0.8438	2000.0000
12	1.1875	3000.0000
13	1.3750	4000.0000
14	1.3688	5000.0000
15	0.0000	0.0000
16	0.3750	500.0000
17	0.6250	1000.0000
18	1.0313	2000.0000
19	1.3750	3000.0000
20	1.7188	4000.0000
21	2.0625	5000.0000
22	0.0000	0.0000
23	0.3438	500.0000
24	0.5938	1000.0000
25	1.0000	2000.0000
26	1.3438	3000.0000
27	1.7188	4000.0000
28	2.1250	5000.0000
29	0.0000	0.0000
30	0.3750	500.0000
31	0.6563	1000.0000
32	1.0625	2000.0000
33	1.6250	3000.0000
34	1.8125	4000.0000
35	2.2188	5000.0000

All data points from Test 1. (Blue curve)

NO. POINTS = 35

X: MEAN= 0.981268571 ST.DEV.= 0.698126419

Y: MEAN= 2214.285714 ST.DEV.= 1754.346343

CORR.COEFF.= 0.982720385

COEFFICIENTS

B(0)= 7.2785

B(1)= 1049.6682

B(2)= 1565.4308

B(3)= -449.0590

R SQUARE = 0.971287243

.NO.	X	Y
1	0.0000	0.0000
2	0.[illegible]750	500.0000
3	0.6250	1000.0000
4	1.0313	2000.0000
5	1.3750	3000.0000
6	1.7188	4000.0000
7	2.0625	5000.0000
8	0.0000	0.0000
9	0.3438	500.0000
10	0.5938	1000.0000
11	1.0000	2000.0000
12	1.3438	3000.0000
13	1.7188	4000.0000
14	2.1250	5000.0000
15	0.0000	0.0000
16	0.3750	500.0000
17	0.6563	1000.0000
18	1.0625	2000.0000
19	1.6250	3000.0000
20	1.8125	4000.0000
21	2.2188	5000.0000

Data of samples in Test 1 that failed away from splice. (Red curve) This curve is probably more representative of cable performance.

NO. POINTS = 21

X: MEAN= 1.050614286 ST.DEV.= 0.735175008
Y: MEAN= 2214.285714 ST.DEV.= 1771.802956

CORR.COEFF.= 0.931080456

COEFFICIENTS

B(0)= -4.8293
B(1)= 1031.4226
B(2)= 1118.7823
B(3)= -240.7754

R SQUARE = 0.991079532

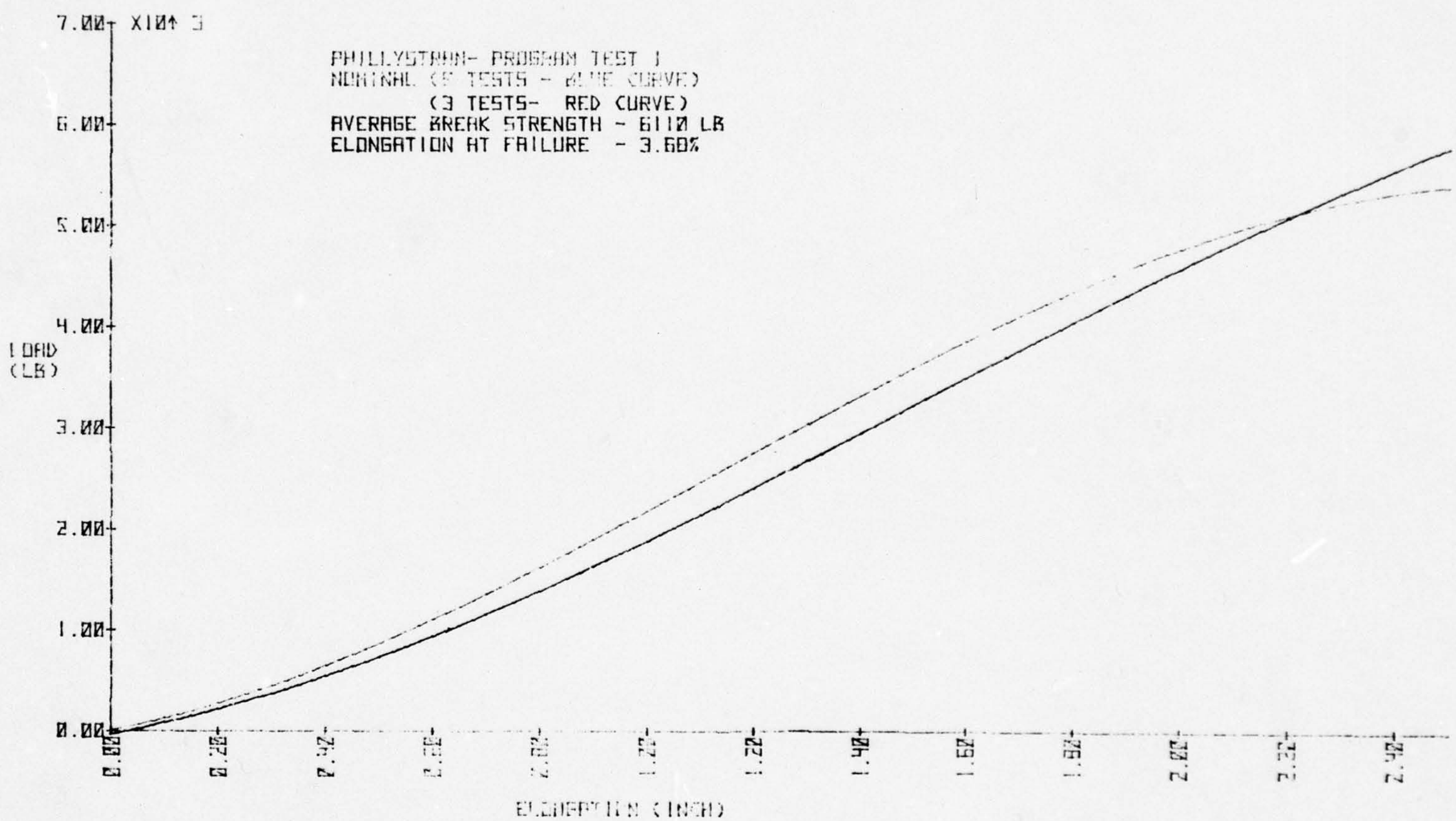

7.00 X10↑ 3
PHILLYSTRAN- PROGRAM TEST 1
(3 TESTS- RED CURVE)
AVERAGE BREAK STRENGTH - 6110 LB
ELONGATION AT FAILURE - 3.60%
6.00
5.00
4.00
LOAD
(LB)
3.00
2.00
1.00
0.00
1.40
2.00

Figure 1b

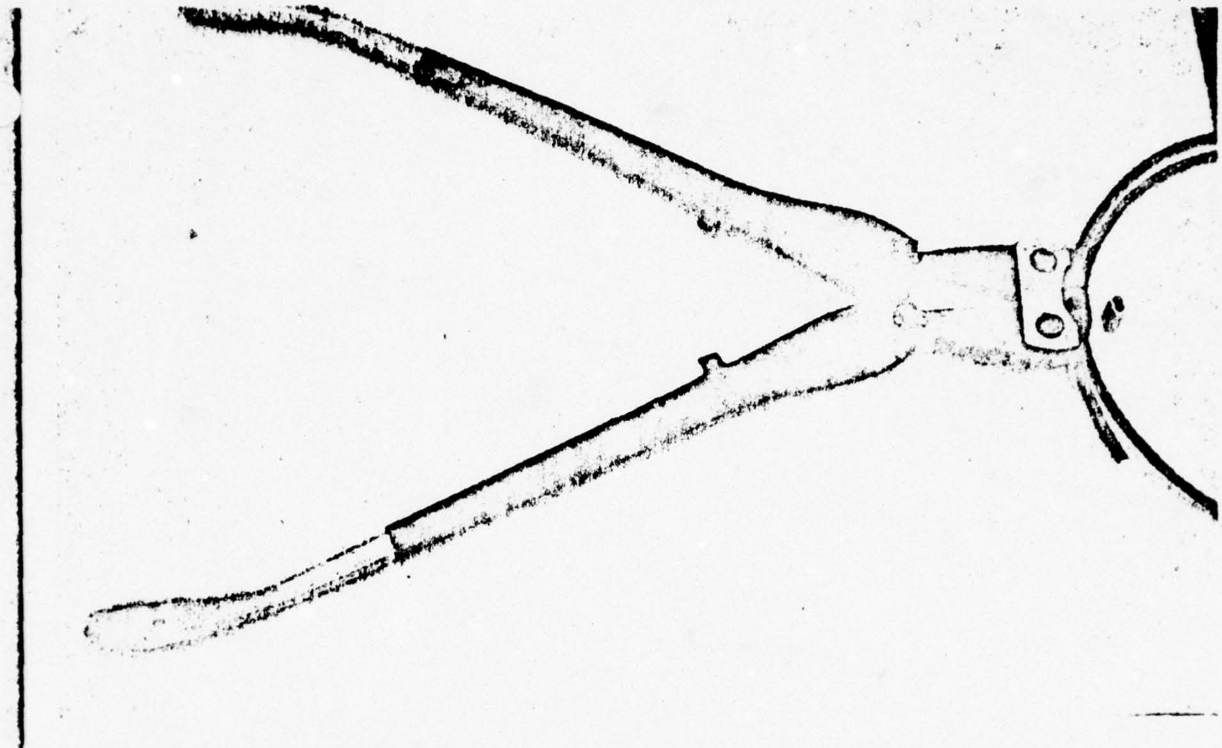
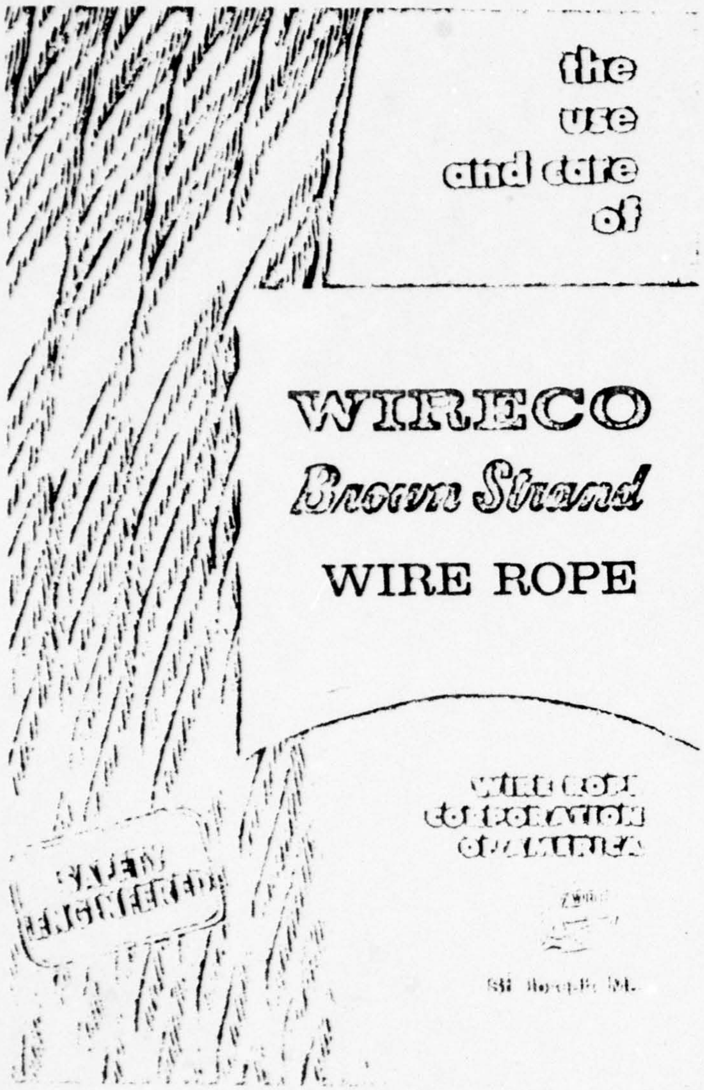


Figure 2a

Figure 2b



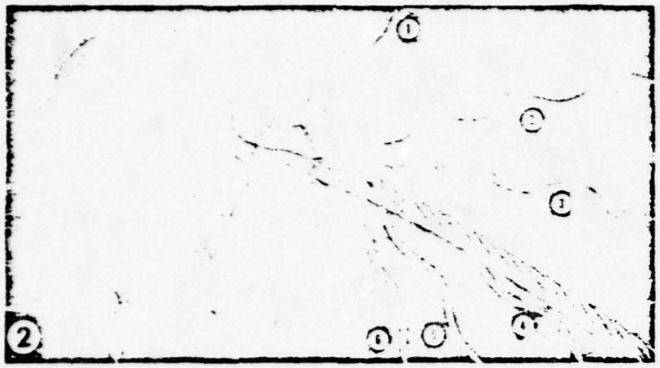
HOW TO SPLICE THIMBLE OR LOOP SPLICE

Splicing a thimble or a loop into a rope consists of bending the rope around the thimble or hight of the loop and splicing the dead end by tucking the strands under the consecutive strands of the live end. We recommend that each strand be given one forming and three full tucks on ropes with strands containing not more than twenty-five wires. Where the strands contain more than twenty-five wires we recommend one forming and four full tucks. The length of the dead end is usually equal to thirty times the rope diameter in inches. A Riggers Vise is best suited for eye splicing although a common Bench Vise can be used.

1. Measure off the length of rope to be used for making the splice. Bend the rope about the thimble and place in vise as shown in figure (1). When facing the vise the dead end of the rope is to the RIGHT of the live end and the correct position for the splicer is to the LEFT.

2. Remove the seizings from the dead end of the rope and unlay the rope back to the thimble. Cut off the fiber core up close to the thimble. See figure (2)

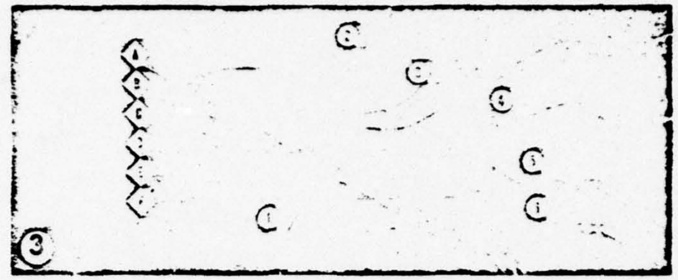
Figure 3



2

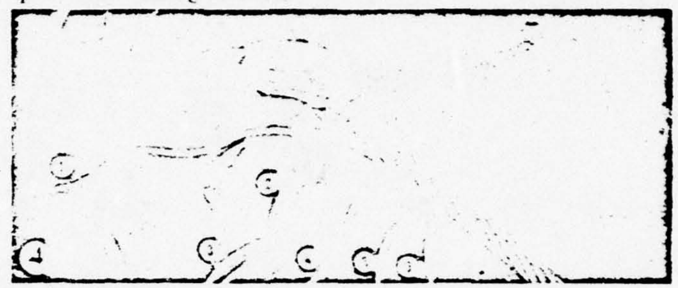
3. Insert a marlinespike under the first two strands nearest the point of the thimble, strands A and B. Rotate the spike half a turn away from the thimble. Insert the end of strand (1) through the opening and pull tight. Rotate the spike back toward the thimble taking strand (1) with it and pull tight. Strand (1) has now had a forming tuck. See figure (3).

Insert marlinespike under strands B and tuck strand (2) by the same method. Tuck strand (3) by inserting the spike under strand C. Give strands 4, 5, and 6 one tuck each under strands D, E, and F respectively. Each of the strands has now received one forming tuck as shown in figure (4) on next page, strand (1) under (A); strand (2) under (B); strand (3) under (C) etc. Now give each strand three additional tucks under its respective strand. Each tuck is made by rotating the marlinespike a half turn, pulling the strand through the opening and rotating the spike back toward the thimble to tighten the tuck.



3

After all tucks are completed trim the ends close and serve the splice with seizing strands.



4

On larger diameter ropes in order to have a taper on the splice it is customary to split the strands on the last two tucks.

Efficiency of Hand Tucked Splices

Rope Diameter	Efficiency	Rope Diameter	Efficiency
1/4	90%	9/16	85%
5/16	89%	5/8	84%
3/8	88%	3/4	82%
7/16	87%	7/8 & Up	80%
1/2	86%		

55

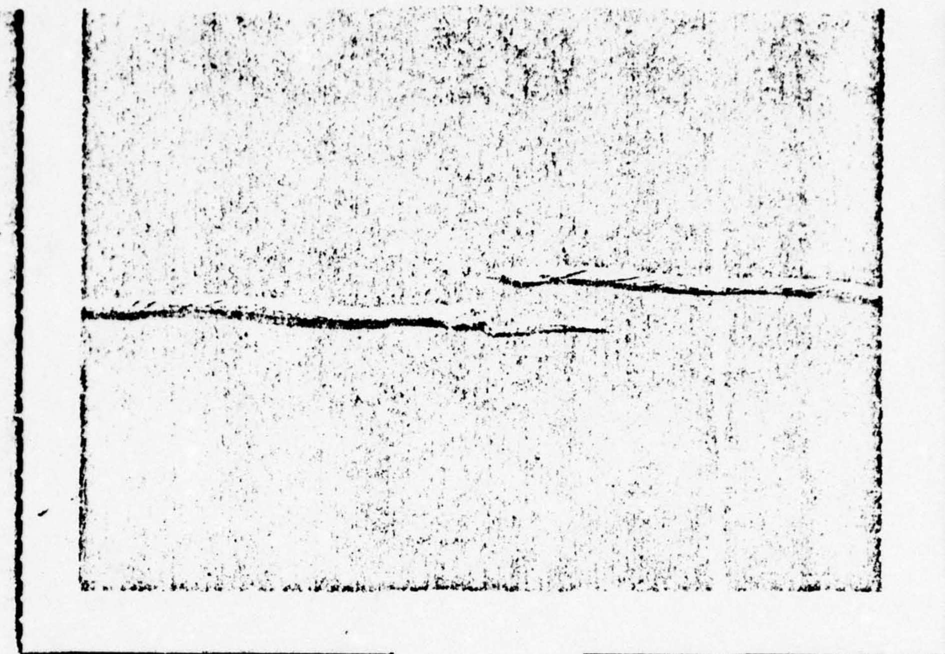


Figure 4a

Figure 4b

Figure 5a

Figure 5b

APPENDIX A

For a nominal 1/4" diameter 7x7 cable, the center of each outer strand is offset about .0833 inch from the cable centerline. Since each outer strand goes through one complete helix revolution in 2.43 inches, its centerline will be .05577 inches longer than the center strand centerline each revolution.

Helix length = 2.43"

Helix circumference = .5236"

$$\delta = \sqrt{(2.43)^2 + (.5236)^2} - 2.43 = .05577"$$

In a six foot sample, there are 31.3 helix cycles. Total difference in elongation of an outer strand would then be 1.7456 inches, or the outer strand length would be 73.7456 inches, while the center strand length is 72 inches.

Compatibility requires that the elongation of outer and center strands be the same during loading. Using axial loading theory:

$$\delta_1 = \delta_2$$

$$\frac{P_1 L_1}{A_1 E_1} = \frac{P_2 L_2}{A_2 E_2}$$

where subscript 1 denotes the center strand, subscript 2 denotes all of the outer strands.

The modulus of elasticity is the same for all strands

$$E_1 = E_2$$

and the areas are related by

$$6A_1 = A_2$$

The lengths L_1 and L_2 are as determined above, and we are interested in the relationship between loads P_1 and P_2.

$$\frac{P_1(72)}{A_1} = \frac{P_2(73.7456)}{6A_1}$$

or $P_1 = .17P_2$

If all strands carried equal loads, the relationship would be

$$P_1 = .1667 P_2$$

NOTE: The above calculations are based on one dimensional axial load, purely elastic deformation.

At a cable load of 6600 lb, the center strand would be loaded to 959 lb, compared to 943 lb if load were evenly distributed over the seven strands. This difference is not very significant. However, the six outer strands squeeze in upon the center strand, superimposing transverse compressive stress on the axial tensile stress. The resultant stress could be significantly higher, but this stress would be somewhat difficult to quantify.

Due to similar construction, the center filament of each strand is subjected to the same variation in load distribution as discussed above.

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WATER ABSORPTION DATA

ON

CORTLAND ROPE

(.25 in diameter, 7000 lb break strength)

2 October 1975

OBJECTIVE

To establish the water absorption rates for the Cortland rope.

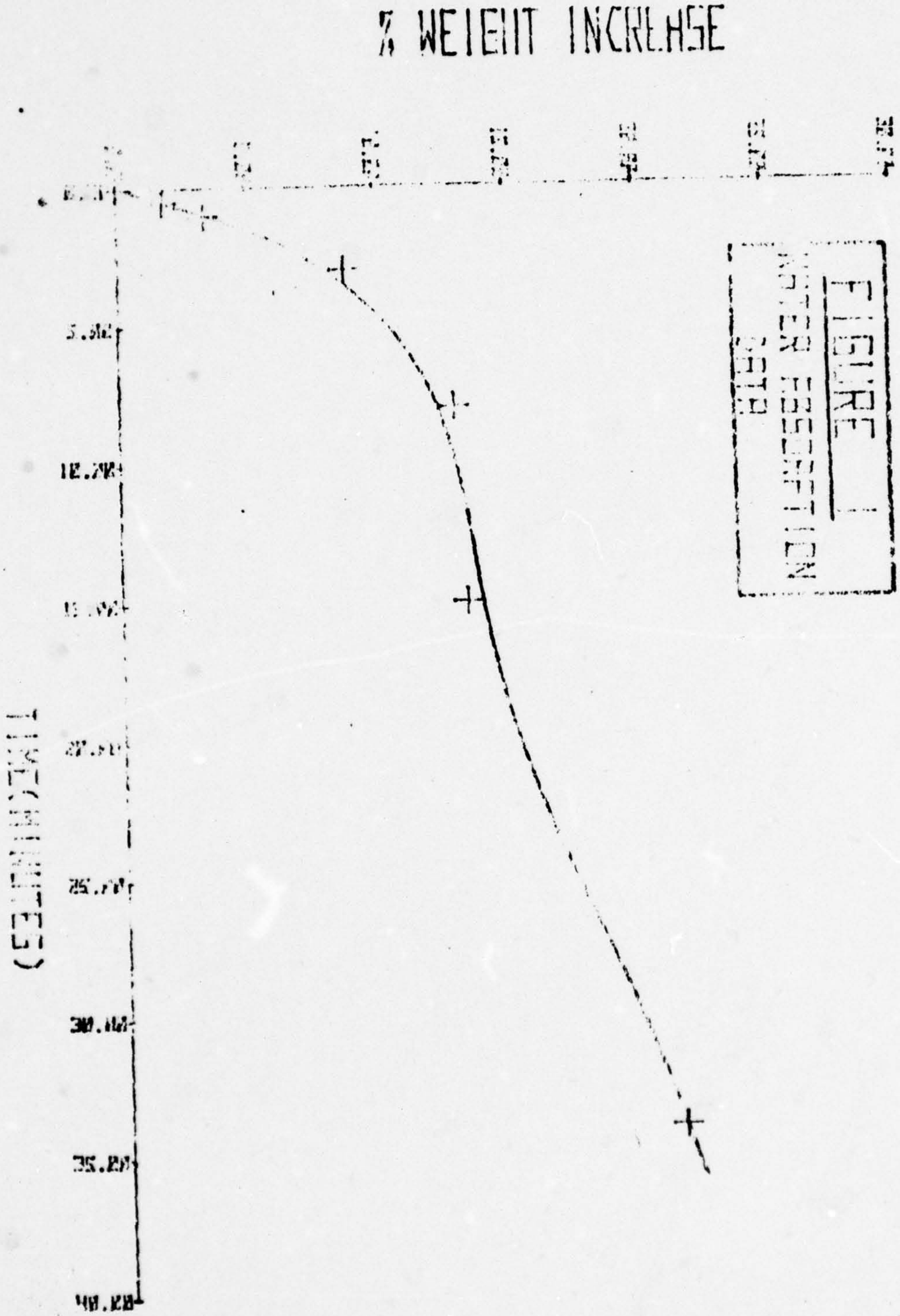
PROCEDURE

The same procedure was used as on the tests of SAMSON and PHILLYSTRAN cables (reference 18 April 1975 seport).

RESULTS

Tests were run on the Cortland rope both with the pootective jacket in place and with the jacket cut. The cut was approximately one inch in length and was to check for any appreciable difference in absorption rates with a damaged jacket. No significant difference was noted. The data recorded is shown below and is plotted in Figure 1.

Time	W_i(g)	W_f(g)	% Increase
30 sec.	14.6	14.8	1.8
1 min.	14.8	15.3	3.4
3 min.	14.7	16.0	8.8
8 min.	14.6	16.5	13.0
15 min.	14.9	16.9	13.4
34 min.	14.9	18.1	21.5
7 days	14.9	19.8	32.9


% WEIGHT INCREASE
TIME (MINUTES)
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
FIGURE
WATER ABSORPTION DATA

63

BREAK STRENGTH TESTS

OF

END TERMINATIONS

ON

CORTLAND ROPE

30 October 1975

OBJECTIVE

To establish the break strength of Kevlar rope terminated with potted end fittings.

PROCEDURE

Ten test samples of Kevlar rope were provided by Cortland Line Company for testing. All samples were four feet in length and terminated on both ends with steel end fittings into which the rope fibers were potted with epoxy resin. Five samples (test 1 through 5) were constructed with 18 strands, rated at 7000 pound minimum break strength. Five samples (tests 6 through 10) were constructed with 36 strands, rated at 14,000 pound minimum break strength.

Each rope was loaded to failure at a slow loading rate of 2000 pounds per minute. The following data was recorded:

(a) Mild snaps (MS) heard during loading, most probably caused by shear in small areas of epoxy outside the fitting (a small amount of epoxy had leaked from the fittings onto the rope in all samples).

(b) Snaps (S) heard during loading which were loud enough to indicate possible failure of some Kevlar fibers or slippage in the epoxy, but not sufficient to cause a drop in load.

(c) Drop back (DB) in load, accompanied by loud snaps, which indicates sufficient fiber or epoxy failure to allow an abrupt and significant lengthening of the test sample.

(d) Failure load, which is the highest load achieved by the test sample prior to separation of most strands from the end fitting.

RESULTS

Test	Load (pounds)
#1	5900 MS
	7200 S
	7320 failure
	strands broke below fitting, both ends
#2	5500 MS
	7900 S
	8180 failure
	strands broke below fitting

Test	Load (pounds)
#3	3600 S
	7160 S
	7220 S
	7400 failure
	strands broke below fitting
#4	6000 S
	7240 S
	7400 failure
	about 1/4 of the strands pulled out of fitting
#5	7480 DB
	7570 failure
	strands broke below fitting
#6	8500 S
	9600 DB
	10,000 S
	12,300 DB, multiple S
	12,450 failure
	almost all strands pulled out of epoxy in fitting
#7	7000 MS
	8500 MS
	12,200 S
	15,200 DB
	16,800 failure
	strands broke below fitting
#8	7000 MS
	13,150 DB
	13,400 failure
	about 1/4 of the strands pulled out of fitting
#9	8500 MS
	10,500 MS
	11,350 S
	11,500 DB
	12,150 failure
	1/2 of the strands pulled out of fitting
#10	10,200 MS
	11,000 MS
	13,500 DB
	14,800 DB
	14,850 failure
	epoxy split in two places in fitting

COMMENTS

Samples 1 through 5 all met the minimum break strength of 7000 pounds. (Actual break strength of the rope is undetermined, since all failures occurred in the end fittings.) Failures occurred essentially one strand at a time, indicating less than optimum load distribution near the end fitting. The epoxy resin was relatively brittle and did not allow much geometry change in the region of the fitting.

Samples 6 through 10 did not all meet the minimum break strength of 14,000 pounds. Failures at lower load occurred due to rope strands pulling out of the end fittings. The ends were potted by dividing the entire rope inside the fitting into two bundles, then pouring the epoxy into the fitting. The inner fibers in each bundle were not saturated with epoxy and thus did not lend much to strength. The fittings seem to be very inefficient but should be adequate for terminating the 7000 pound break strength rope.

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WATER ABSORPTION DATA

of

SAMSON (KEVLAR 29) BRAIDED CABLE

0.3 inch diameter
32 pounds/1000 feet

and

PHILLYSTRAN (IMPREGNATED KEVLAR 29) CABLE

0.25 inch diameter
33 pounds/1000 ft

18 April 1975

TABLE OF CONTENTS

LIST OF FIGURES

OBJECTIVE

To establish the water absorption rates for the SAMSON and PHILLYSTRAN cables.

EQUIPMENT

Water tank

Ohans, Triple Beam Balance, 2610 g capacity

PROCEDURE

Five series of tests were performed measuring the percentage weight increase versus time for a completely submerged rope. The five tests were on:

a. SAMSON without nylon jacket

b. SAMSON with jacket

c. PHILLYSTRAN with polyurethane jacket

d. PHILLYSTRAN with a 5/8" slit in the jacket

e. PHILLYSTRAN without jacket

Rope samples varied from 12 inches to 18 inches in length. The ends were sealed with paraffin wax so that water would be absorbed radially rather than axially. Tests were performed under the following conditions:

a. Room temperature - $70^{\circ}F \pm 5^{\circ}F$

b. Water temperature - $18^{\circ}C$

c. Humidity was about 30%

All data plots were performed on an HP-9830 computer using polynomial regression to achieve a least-square fit.

TEST 1

The first test was performed on SAMSON without its nylon jacket. Ten samples were used, each approximately 15 inches in length. The samples were weighed before and after immersion in the water tank and the percent weight increase was obtained. The data is shown below and plotted in Figures 1, 2, and 3.

Orig. Weight (g)	Time	Final Weight (g)	% Increase
10.8	10 sec	12.9	19.4
11.6	20 sec	14.7	26.7
11.7	40 sec	16.1	37.6
11.6	1 min	16.0	37.9
11.6	2 min	16.6	43.1
11.7	5 min	17.7	51.3
11.7	10 min	18.0	53.8
11.7	20 min	18.1	54.7
11.7	30 min	18.5	58.1
11.7	60 min	20.2	72.6
11.7	4 days	21.4	82.9

COMMENTS - TEST 1

The data above shows that large amounts of water were absorbed by the SAMSON cable without its protective jacket. The results are somewhat misleading, however, due to the fact that the rope was completely submerged in water and under no tension.

First, the rope should not be subjected to this degree of saturation under normal operating conditions. Also, much of the water absorption was due to the radial expansion of the rope after immersion. When the cable is under load, the tension should prevent this expansion by reducing the air space around the fibers and thus reducing the volume of water that can be absorbed. As will be shown below, the nylon jacket keeps the rope fibers close together and greatly reduces the water absorption rate and volume.

TEST 2

The second test was performed on SAMSON with its nylon jacket in place. The same procedure was followed as in Test 1 on ten samples of cable. The results are shown below and in Figures 1, 2, and 3.

Orig. Weight (g)	Time	Final Weight (g)	% Increase
20.1	10 sec	21.7	7.9
20.4	20 sec	22.3	9.3
20.6	40 sec	22.8	10.7
20.8	1 min	23.6	13.5
20.5	2 min	24.0	15.4
20.5	5 min	24.0	17.1
20.5	10 min	24.3	18.5
20.5	20 min	24.3	18.5
20.5	30 min	24.5	19.5
20.5	64 min	25.0	22.0
20.5	6 days	25.6	24.9

COMMENTS - TEST 2

This test points out the advantage of using the nylon jacket on the SAMSON cable. The jacket keeps the fibers close together and prevents the large weight increases experienced without the jacket.

TEST 3

This test was performed on the PHILLYSTRAN cable with its polyurethane jacket in place. No appreciable increase in weight was found. The original weight of a 12 inch sample was 15.1 grams and after 60 minutes its weight was 15.2 grams. The PHILLYSTRAN can thus be considered virtually waterproof with its jacket in place.

TEST 4

Test 4 was performed on the PHILLYSTRAN cable with its jacket but a 5/8 inch slit was cut through the jacket in line with the twist of the rope. The original weight of the 12 inch sample was 14.9 grams. The results are shown below and in Figures 4 and 5.

Time	Final Weight (g)	% Increase
10 sec	15.1	1.3
20 sec	15.1	1.3
40 sec	15.1	1.3
1 min	15.2	2.0
2 min	15.3	2.7
5 min	15.3	2.7
10 min	15.4	3.4
20 min	15.75	5.7
40 min	15.9	6.7
60 min	16.0	7.4
4 days	17.7	18.8

COMMENTS - TEST 4

This test was performed to see the effect of small cracks in the protective jacket of PHILLYSTRAN. The results show that a small slit will produce only small weight increases based on reasonable periods of exposure.

TEST 5

The final test was performed on PHILLYSTRAN with its protective jacket removed. Eight 12 inch (approximately) samples were used and the procedure was the same as in Test 1. The results are shown below and in Figures 4 and 5.

Orig Weight (g)	Time	Final Weight (g)	% Increase
10.7	20 sec	12.4	15.9
10.3	40 sec	12.2	18.4
10.3	1 min	12.4	20.4
10.2	2 min	12.8	25.5
10.1	5 min	12.7	25.7
10.0	10 min	12.8	28.0
9.9	33 min	13.0	31.3
9.9	71 min	13.2	33.3
9.9	4 days	14.75	49.0

COMMENTS - TEST 5

The data of Test 5 illustrates the increased water absorption of PHILLYSTRAN without its protective jacket. The absorption rates of PHILLYSTRAN are considerably lower than the corresponding ones are for SAMSON.

CONCLUSIONS

Based on the data gathered, PHILLYSTRAN cable absorbed much less water than did SAMSON cable for all conditions. The polyurethane jacket on PHILLYSTRAN was virtually water repellant, however, it is possible that the jacket could crack at very low atmospheric temperatures and cyclic loads. The maximum percentage weight gain for the SAMSON cable with its jacket was almost one half of that of PHILLYSTRAN without its jacket (24.9% versus 49.0%). If further testing verified that the polyurethane jacket would crack at low temperatures, the nylon jacket as used on the SAMSON cable would have to be preferable.

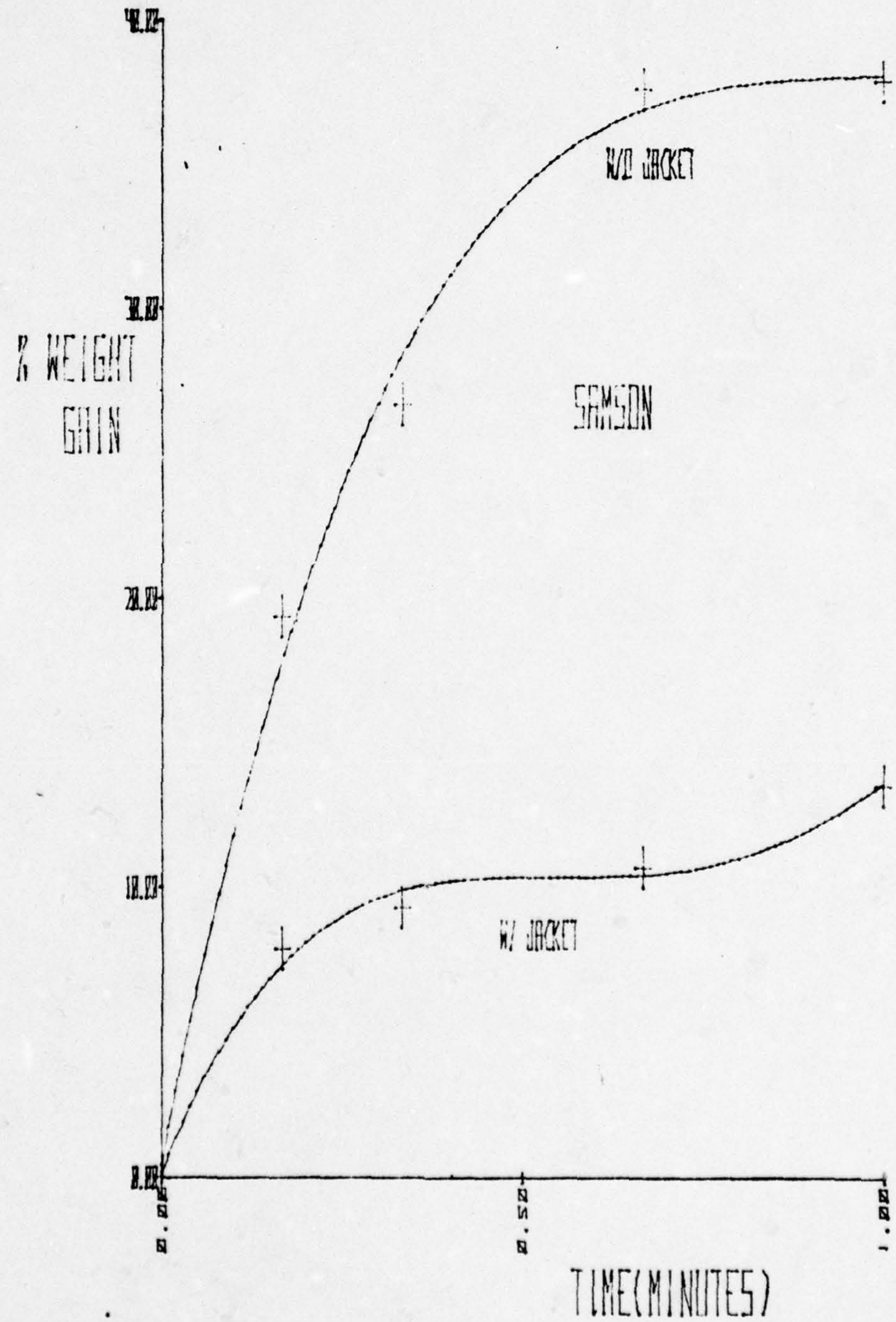

FIG. 1 - Water Absorption Characteristics of SAMSON Cable

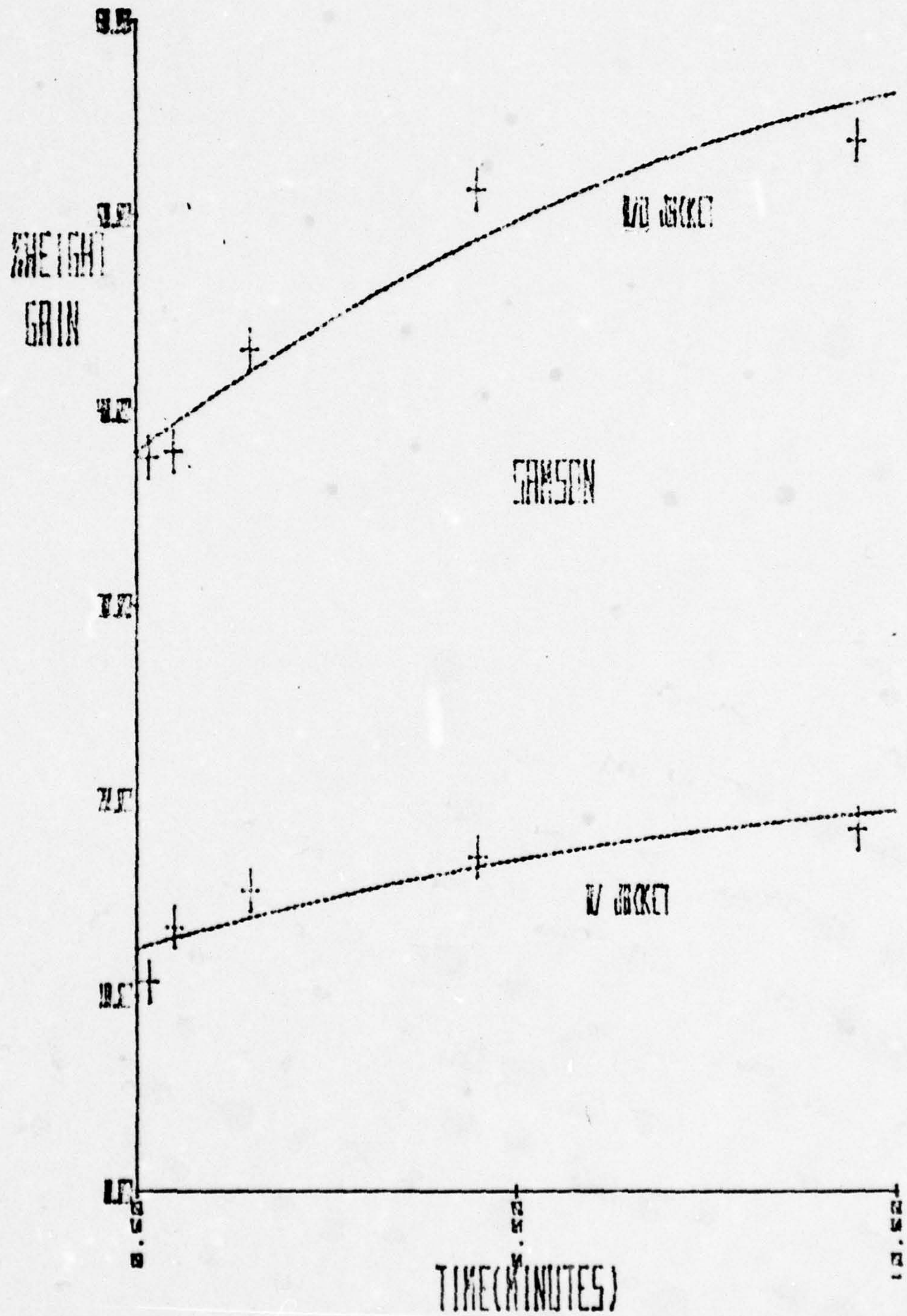

FIG. 2 - Water Absorption Characteristics of SAMSON Cable

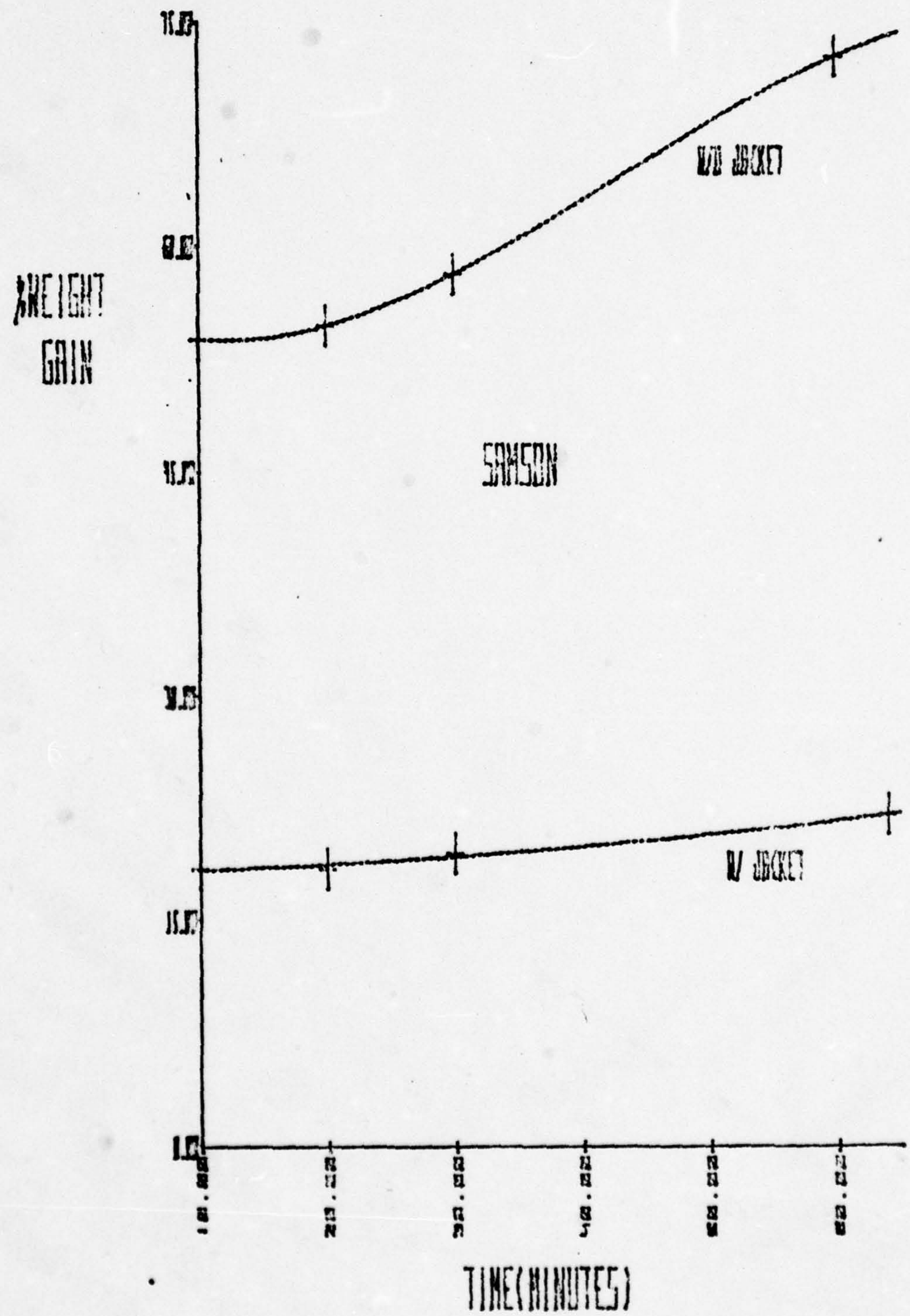

FIG. 3 - Water Absorption Characteristics of SAMSON Cable

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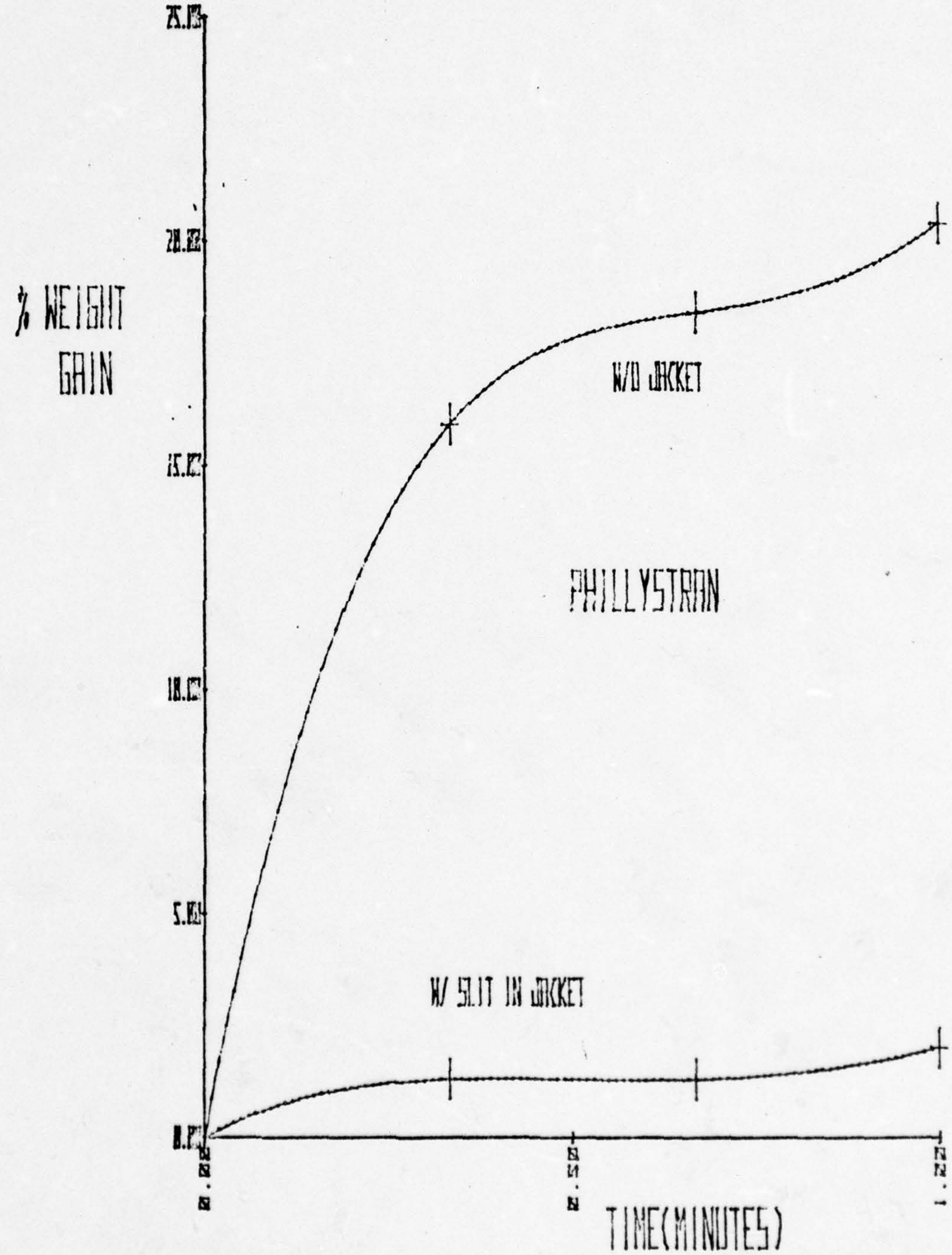


FIG. 4 - Water Absorption Characteristics of PHILLYSTRAN Cable

T8

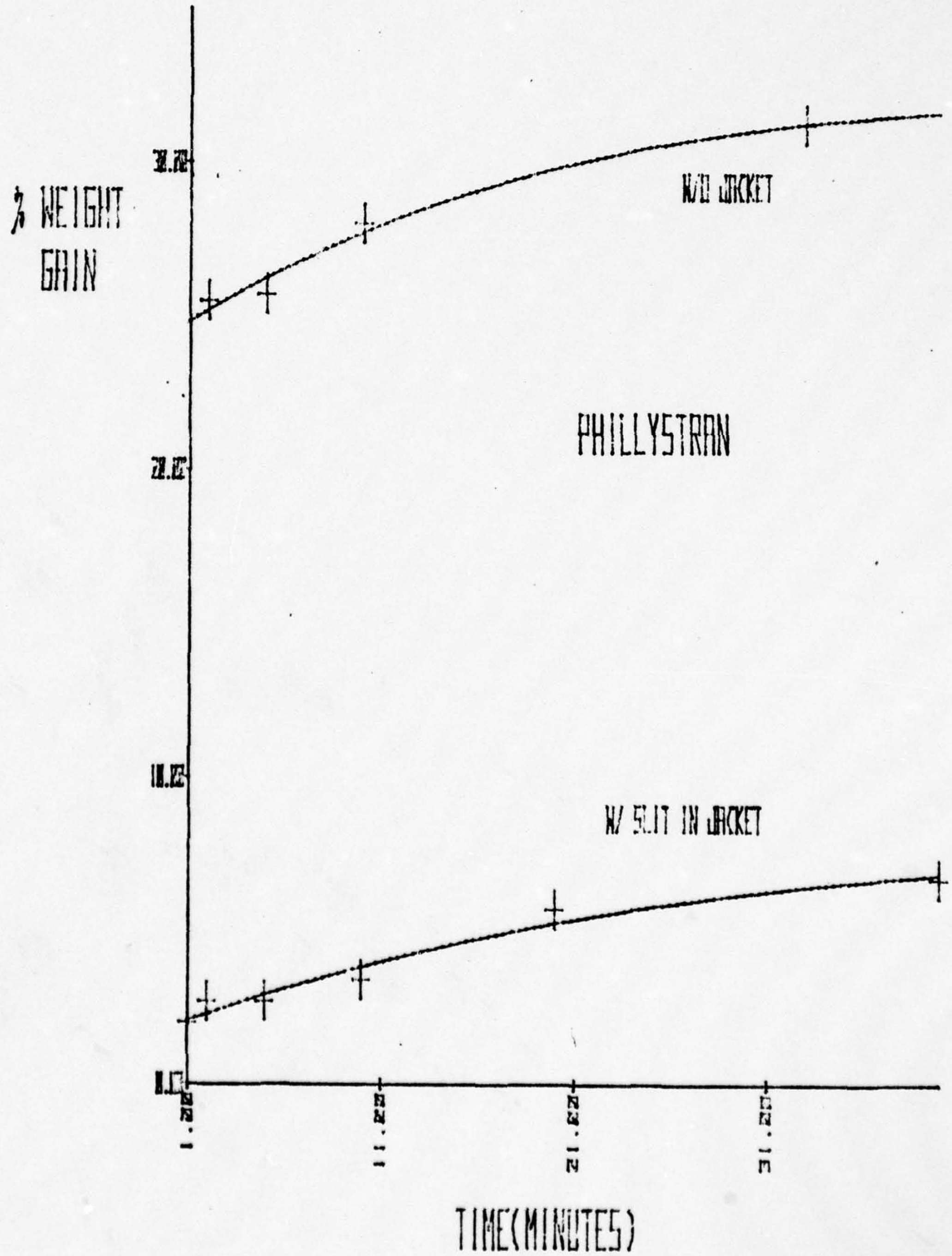


FIG. 5 - Water Absorption Characteristics of PHILLYSTRAN Cable

79

EYE SPLICE

FOR

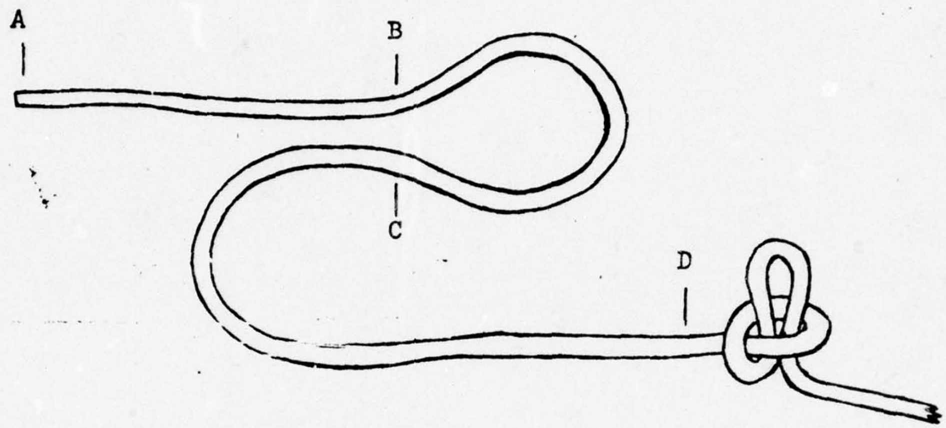
SAMSON BRAIDED ROPE

by

Donald L. Hausam

January 1976

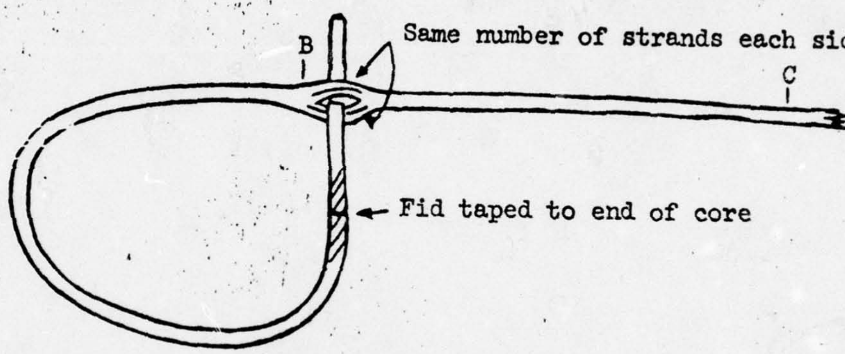
STEP 1: Making the Measurements



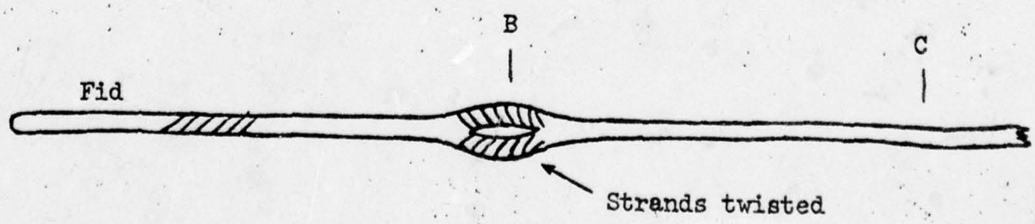
The distance A-B is the length of tail that will be buried inside the core after the splice is complete. (See Comments.) The distance B-C is a loop the size of the eye desired. If using a thimble, form the loop around the thimble. Tie a slipknot in the rope at D, about 10 feet from the end of the rope. Cut through the jacket at C, being very careful not to damage any of the fibers of the core, and slip that part of the jacket off the rope, exposing the core from C to the end. Re-mark B on the core.

STEP 2: Making the Eye

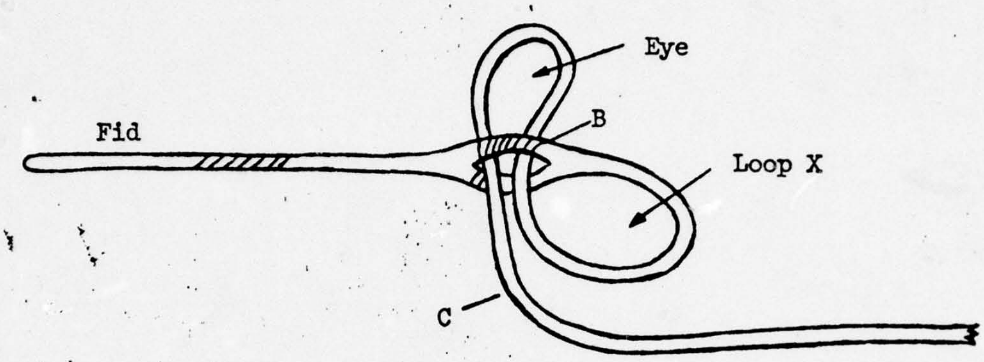
Wrap a layer of tape around the end of the core to keep it together. Then place the end of the core into the open end of the tubular fid and tightly tape the two together. Open the core at B and pass the fid through the core at B, making sure there are the same number of strands on each side of the fid.



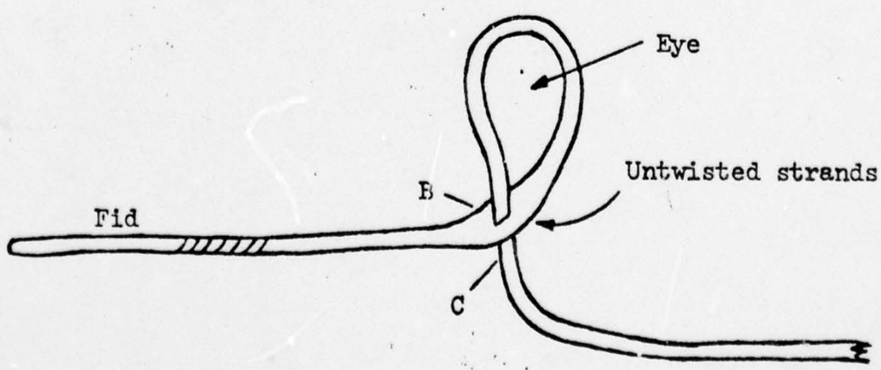
Continue pulling the fid and core through at B until the core is completely pulled through and straight, leaving a "hole" in the core at B with a twist in the strands on either side of the hole at B.



Take the core between B and C and push it through the "hole" at B, going through the core in the same direction that the fid was pulled through. Do not snag any strands during this step. (See

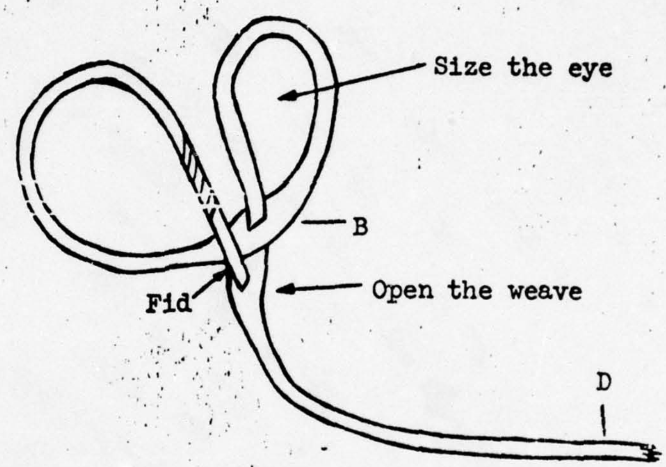


Continue pulling on the core in the region of the eye so that Loop X is pulled through the hold at B and disappears. If the core between B and C was passed through B in the proper direction, the strands will untwist at B when Loop X is pulled through. If the strands at B twist more, you went through B in the wrong direction. Pull the eye back out of B and push the core through the hole at B in the other direction.

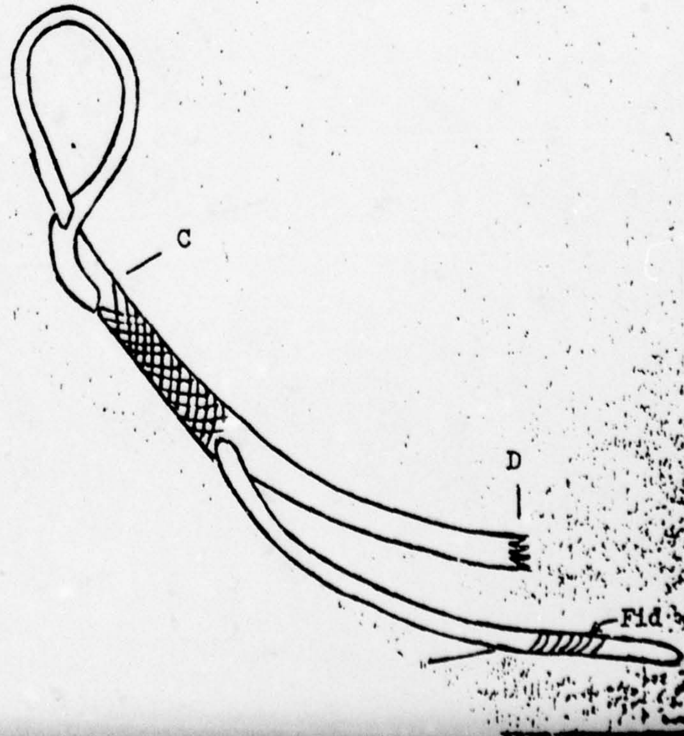


STEP 3: Burying the Tail

Size the eye around a thimble or to the desired size. Open the weave of the core just below the eye (C) and insert the fid into the center of the core.



Pull as much of the core from C to D as possible onto the fid, being careful not to snag any strands. Then bring the tip of the fid back out of the core and pull the fid and slack out as far as possible.



COMMENTS

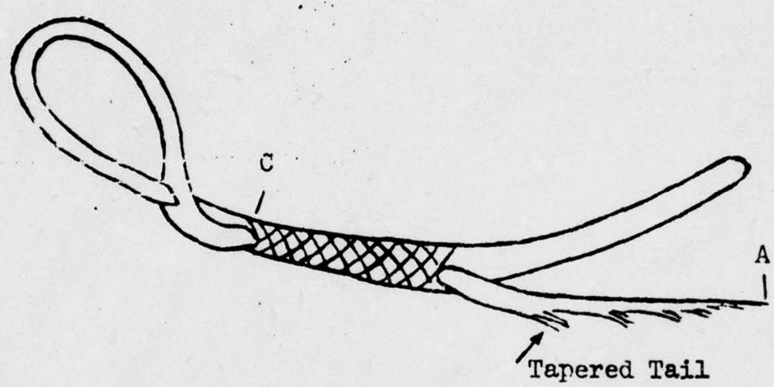
1. In my work with one-quarter inch diameter Samson, a buried tail of 15 inches (length A-B) was sufficient even during cyclic loading. Six inches was the minimum for a static load. The longer the tail, the less chance that the tail will pull out.

2. If any strands are snagged in the weave, they are very difficult to smooth back into the weave. As load is applied, the squeezing action of the weave will not let the snagged strand smooth itself out and that strand will break prematurely. The break strength of the rope is thus reduced by snags.

3. The smoother the taper of the tail, the less chance the rope will break at the splice. I got 100% efficiency out of the splice by cutting two strands at a time evenly over a distance of eight inches in a 12-strand rope. A blunt tail (no tapering) will give about 80-85% efficiency.

STEP 4: Tapering the Tail

Remove the fid from the end of the core. Start tapering the core about halfway between C and A by cutting one or two strands at a time evenly spaced until reaching A. (See Comments)



While holding the eye, grasp the core just below the eye and milk the core down toward D. The tail will be drawn back inside the core as you do this. Untie the knot at D and the splice is complete.

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COMPARATIVE STUDY

OF

BASIC STRENGTH CHARACTERISTICS

OF

CORTLAND (KEVLAR 29) ROPE

AND

PHILLYSTRAN (KEVLAR 29) BRAIDED ROPE

6 February 1976

OBJECTIVE

To establish the relative strengths and the strength degradation of similarly rated Cortland and Phillystran ropes resulting from cyclic loading imposed on the ropes during flight tests at White Sands Missile Range, New Mexico.

EQUIPMENT

Tinius-Olsen 120,000 Super L tensile test machine
Nicopress aluminum crimping connectors and crimping tool

PROCEDURE

1. The following test data pertains to Cortland rope, 18 strands of Kevlar 29 in a black braided protective jacket, with a rated break strength of 7000 pounds.

A nominal break strength of new rope was established by loading to failure 10 samples of rope which were in new condition (no prior loading history). A nominal break strength of the used rope (rope that was flown in November 1975 at WSMR) was also established by loading to failure 10 total samples of this rope. Five samples were taken from the end of the rope that had been nearest the traction drive, and five samples were taken from the end nearest the fair lead. All loading rates used were slow (less than 2000 pounds per minute). All end terminations were braided eyelets similar to those made on the Cortland rope during field testing at WSMR.

Cortland (control samples)

Test	Break Strength (pounds)	Remarks
1	9300	4 strands in line failed
2	9000	1 strand in line failed
3	8900	
4	7900	bottom splice slipped, then failed
5	7920	one strand failed at a time
6	8280	bottom splice slipped, then failed
7	9500	failure in splice
8	9460	failure in splice
9	8400	failure in line
10	8900	failure in splice

Cortland (end of rope nearest traction drive)

Test	Break Strength (pounds)	Remarks
11	8070	2 slips, then failure in splice

12	7650	slips in splice
13	7200	single strands in line
14	8700	1 slip at 7800 lb
15	9600	abrupt failure in splice
	Cortland (end of rope nearest fair lead)	
16	8900	2 slips, then failure in splice
17	7670	single strands in line
18	8020	failure in line
19	7820	slips in splice
20	7680	failure in line

Remarks for Cortland

Equalizing tension of all strands in the splice was difficult. If the splice slipped once or twice at lower loads, however, the tension was equalized by the slippage. The rope would then fail abruptly in the splice through half the strands. If the splice did not slip during loading, the failure generally occurred in one strand away from the splice at a fairly low load. If the splice slipped at high load, the rope heated severely in the region of the slippage (gray smoke was given off). Strength loss due to this heating and abrasion would be hard to estimate.

Statistical analysis could be performed on the test data, but the results would not be too meaningful due to data scatter. Tests 7, 8 and 10 were very similar in that no slippage occurred and failure was abrupt in the splice. Test sample 15 failed in identical fashion. Tests 16 through 20 are rather inconclusive. If you compare break strengths of new and used ropes based on mode of failure (slips in splice before failure, failure in line) you will see that the results are similar.

2. The following test data pertains to Phillystran rope, four cores of braided Kevlar 29 with resin impregnation in an extruded polyurethane jacket, with a rated break strength of 7000 pounds

A nominal break strength of new rope was established by loading to failure five samples of rope which were in new condition (field test #2). A nominal break strength of the used rope was also established by loading to failure five samples of rope taken from field test #3. All loading rates were slow. All end terminations were eyelets formed using Nicopress connectors crimped against the core of the rope (jacket removed to prevent slippage).

Phillystran (samples from field test #2)

Test	Break Strength (pounds)
21	6000
22	5570
23	6160
24	5870
25	5780

Phillystran (samples from field test #3)

26	5170
27	5740
28	4970
29	6300
30	5860

Remarks for Phillystran

The crimping connectors cause a triaxial state of stress in the rope which is greater than the state of stress away from the end terminations. Each of the ropes (except test 28) had an abrupt failure through the entire rope at the point that the rope left the connector away from the eyelet. Only the outer core of test 28 failed, indicating that the outer core carried most of the load to failure. Test 28 data should probably be disregarded.

Statistically there was a strength reduction of 2% (if test 28 is disregarded), and data scatter is on the order of 10%. The interesting point to note is that the highest break strength in 10 tests occurred on test 29 which was performed on used rope.

COMPARISON OF PHILLYSTRAN AND CORTLAND

I would conclude from the tests that no strength degradation occurred in either rope due to usage in the field. I was, however, rather concerned about the low break strength of Phillystran as compared to Cortland. The weight of Cortland (with jacket) is about 26.9 lb/1000 feet compared to 30.7 lb/1000 feet for Phillystran. In order to determine strength to weight ratios, I needed to know the efficiency of splices used on Cortland and Phillystran. I analyzed Phillystran first.

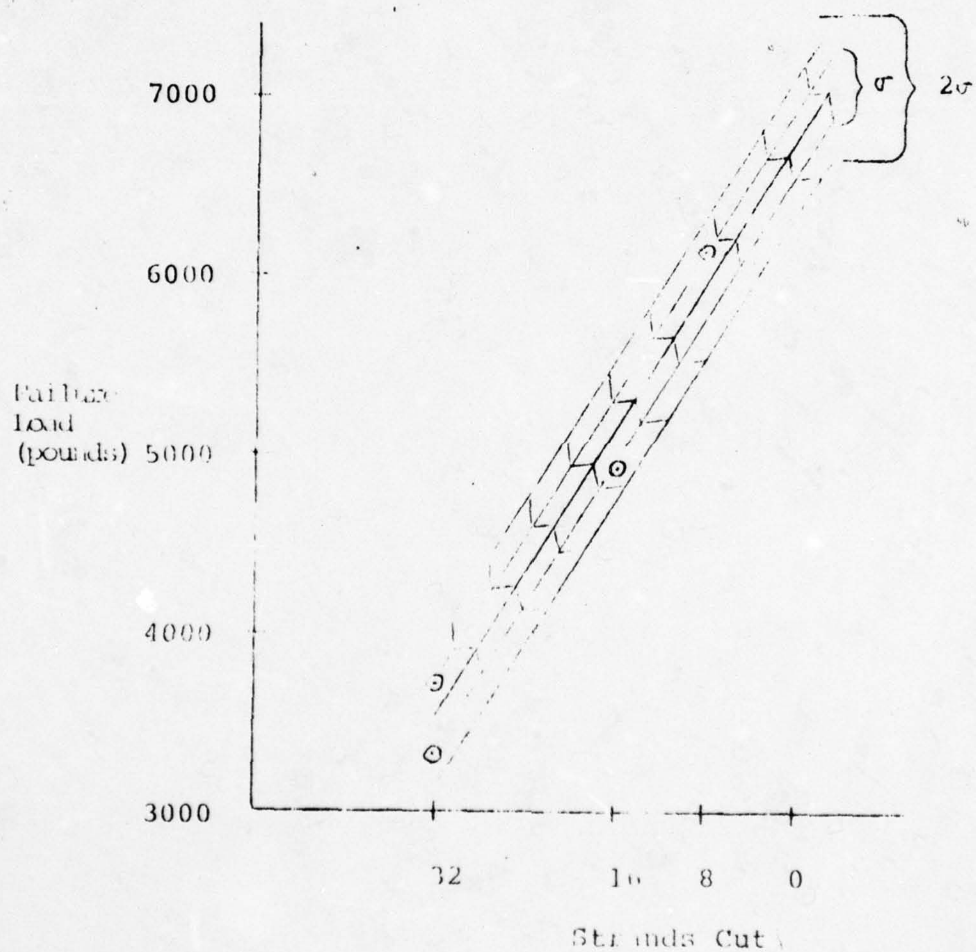
The Phillystran rope is made up of four cores of braiding, one woven over the outside of the other. The first core is 16 strands braided around a white fabric strand (content unknown). The second and third cores are braided using 24

strands each, and the fourth core is made of 32 strands. The strands in the different cores are not the same size, however, so no correlation can be made between number of strands cut in different cores and percent strength loss due to these strands being cut. I assumed that there would be a linear relationship between number of strands cut in the outer core (all strands are the same size in this core) and tested ropes with all outer strands cut (32), 16 strands cut, and 8 strands cut.

# Strands Cut	Break Strength
32	3350 lb
32	3730 lb
16	4920 lb
8	6060 lb

Graph 1 illustrates this data with a projected break strength for the uncut rope. The scatter bands (standard deviation σ) are based upon scatter in the data during tests 21 through 25, since all the failures were essentially the same during these tests. The maximum (95% probability) projected break strength for Phillystran is 7500 lb, giving about 78% minimum efficiency in the splice. Assuming 100% efficiency in the Cortland splice, the Cortland still has a significant strength to weight advantage over Phillystran. The above results yield only a rough approximation, however, due to the limited amount of data points.

I did not estimate a splice efficiency for Cortland.



7000
6000
Failure
Load
(pounds) 5000
4000
3000
σ
2σ
32
16
8
0
Strands Cut

Graph 1

42

THEORETICAL ANALYSIS

OF

STRESSES IN A SMALL DIAMETER ROPE RESULTING FROM SPOOLING THE ROPE UNDER TENSION ONTO A STORAGE DRUM

5 March 1976

Captain Donald L. Hausam

AD-A077 474 AIR FORCE ACADEMY CO F/G 11/9

POLYMER TETHERLINE EVALUATION FOR BALLOON TECHNOLOGY.(U)

SEP 76 D T HAUSAM PRO-803-76177

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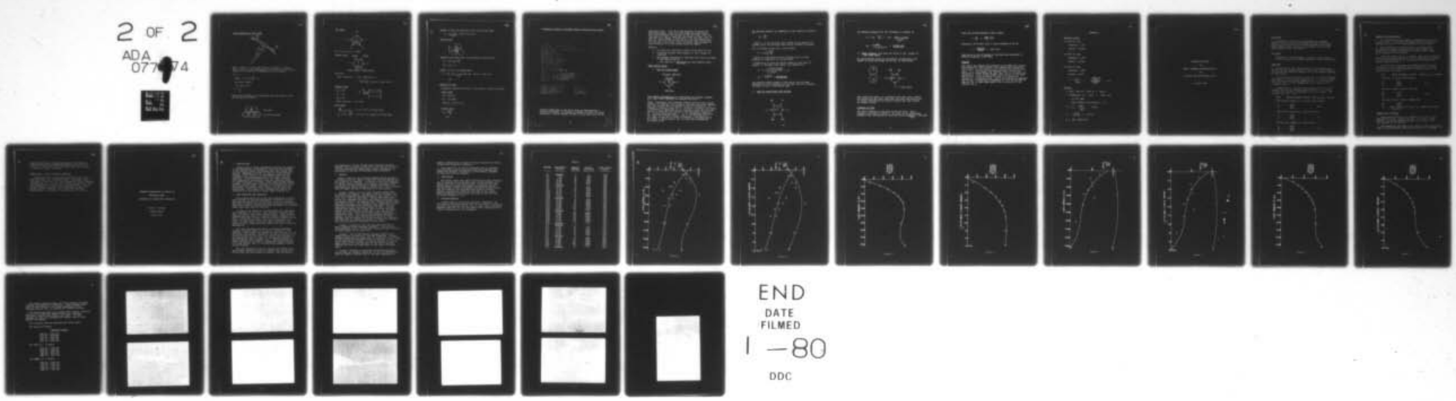

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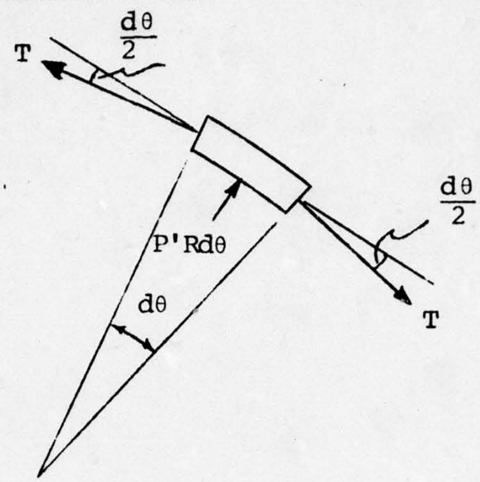
1 -80

DDC

LOAD INTENSITY ON THE LINES



For a segment of line with tension T around a circular drum, radius R, the intensity of force that the line would exert on the drum is P' (pounds per unit strength).

$\Sigma F = 0$

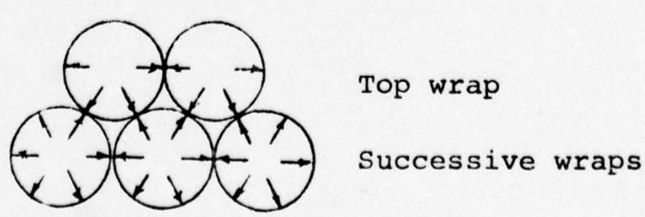
$$P'Rd\theta - 2T \sin\left(\frac{d\theta}{2}\right) = 0$$

for small angles

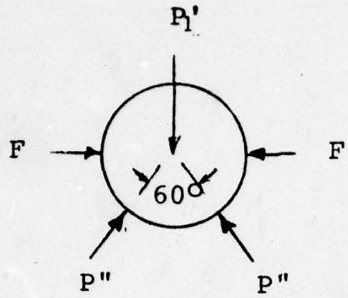
$$\sin(d\theta) \approx d\theta$$

$$P' = \frac{T}{R}$$

This load intensity is transferred from one wrap of line to the next as follows:

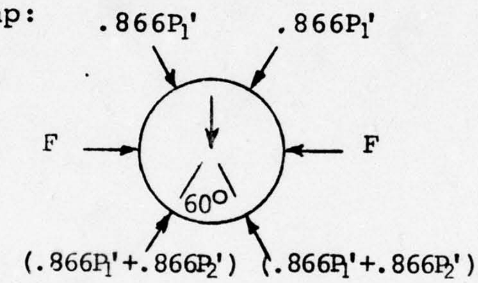


Top wrap:



$P'' = P' \sin 60^o = .866P'$

Second wrap:



Nth wrap:

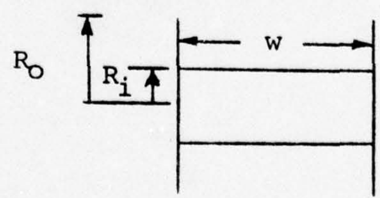
$$\text{Total intensity} = \sum_1^n P'_n \text{ vertically or}$$
$$= .866 \sum_1^n P'_n \text{ at each contact point}$$

STORAGE DRUM:

$R_i = 10"$

$w = 55"$

$R_o = 24"$



Rope diameter = .311 inch

First wrap

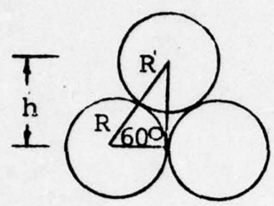
$$\frac{55"}{.311 \text{ inch/line}} = 177 \text{ lines on first wrap}$$

$$R_1 = 10 + \frac{.311}{2} = 10.1555" \text{ to center of first wrap}$$

Number of feet of rope that will go on first wrap

$$2\pi \left(\frac{10.1555}{12}\right)(177) = 941 \text{ feet}$$

<u>Second wrap</u>



Assuming each wrap lays into grooves of prior wrap

$h = .311 \sin 60^\circ$

$R_2 = R_1 + h$

Number of feet in second wrap

$$2\pi \left(\frac{10.1555 + .311 \sin 60}{12}\right) (177) = 966 \text{ feet}$$

etc.

<u>TENSION IN LINE:</u>

Assuming beginning tension of 450 pounds, constant torque:

<u>First wrap</u>

$T_1 = 450$ lb

$R_1 = 10.1555"$

Torque = 4570 in lb

<u>Second wrap</u>

$$T_2 = \frac{4570}{R_2}$$

etc.

A computer program to perform these calculations is below.

```
10 DEG
20 DIM T[60],R[60],F[60],P[60]
30 T1=450
40 PRINT "TENSION IN FIRST WRAP=";T1
50 R1=10.1555
60 P1=T1/R1
70 H1=0.311*SIN(60)
80 F1=941
90 F2=2*PI*177/12
100 FOR N=2 TO 60 STEP 1
110 R[N]=R1+(N-1)*H1
120 T[N]=4570/R[N]
130 F[N]=F2*R[N]
140 F1=F1+F[N]
150 P1=P1+T[N]/R[N]
160 IF F1>75000 THEN 180
170 NEXT N
180 PRINT "TENSION IN LAST WRAP =";T[N]
190 PRINT "NUMBER OF WRAPS=";N
200 PRINT "TOTAL LOAD INTENSITY=";P1
210 PRINT "MAXIMUM RADIUS=";R[N]
220 END
```

```
TENSION IN FIRST WRAP=        450
TENSION IN LAST WRAP =        127.9756764
NUMBER OF WRAPS=              49
TOTAL LOAD INTENSITY=         962.3601172
MAXIMUM RADIUS=               23.08352723
```

Initial conditions in the first wrap are established in lines 30 (tension), 50 (radius to center of line), 60 (load intensity), and 80 (number of feet of rope that will fit on

the first wrap). Line 70 is the increase in radius for successive wraps. Line 110 calculates this new radius. Line 120 calculates the tension in the Nth wrap, line 130 the number of feet of rope that Nth wrap can hold, line 140 sums the total number of feet held in all the wraps up to the Nth, and line 160 terminates the loop when 75,000 feet of line are on the drum. Line 150 totals the increases in load intensity P' as successive wraps are added.

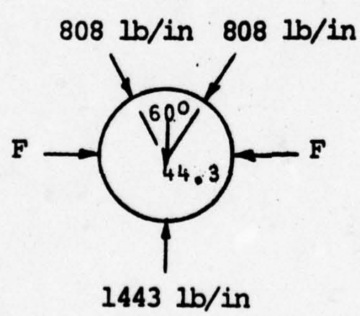
Results:

1. 49 wraps are required to store 75,000 feet of line
2. A maximum storage drum diameter of 46.2 inches is required.
3. The maximum intensity of load that will occur on lines in the bottom wrap is

   .866·(962.36) = 833 lb/in for each contact point

MOST SEVERE CASES:

1. Rope on bottom wrap:



From Theory of Elasticity by Timoshenko and Goodier, McGraw-Hill Inc., 1970, Library of Congress #69-13617

NOTE: Timoshenko lists maximum pressure arising from contact between two spheres, two cylinders, cylinder and plane surface, etc. and relates this to maximum stress in the bodies. He assumes a Poisson's ratio of $\nu = .3$ which is typical for metals. I performed an experiment to get Poisson's ratio for the rope and got a value of 3.45, which is not meaningful (Appendix A). I would speculate that $\nu = .3$ is a reasonable value for the individual Kevlar fibers. Due to the construction of the rope, it may not be valid to analyze in the same way as you would a typical metal, but it's the best information available to me.

The maximum pressure q_o somewhere in the region of contact is

$$q_o = \frac{2P'}{\pi b}$$

where P' is the load per unit length of the surface of contact and b is the half width of the surface of contact.

For a cylinder contacting a flat surface

$$b = 1.52\sqrt{\frac{P'R}{E}}$$

where R is the radius of the cylinder and E is the modulus of elasticity of the cylinder.

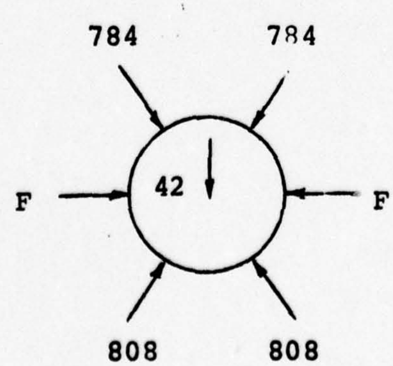
I computed an E value for Kevlar based on test data on Samson, 12 November 1974 report (see Appendix A)

$$b = 1.52\sqrt{\frac{1443\ (.1555)}{5\text{x}10^6}} = .01$$

$$q_o = \frac{2(1443)}{\pi\ b} = \underline{\underline{90,220\text{ psi}}}$$

The maximum normal stress in the region has the same magnitude as this pressure, so the rope would be stressed to about 90 ksi in the bottom wrap.

2. <u>Rope in second wrap from bottom</u>:



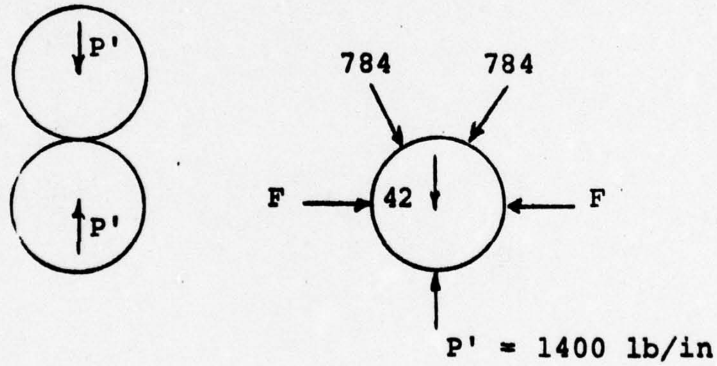
The maximum pressure for two cylinders in contact is

$$b = 1.08 \frac{P'R}{E} = 1.08 \frac{(808)\ (.1555)}{5x10^{6}}$$

$$q_o = \frac{2\ (808)}{\pi\ (5.414x10^{-3})} = \underline{\underline{95,000\ psi}}$$

3. <u>Ropes crossing</u> (one wrap not lying in the groove of the lower wrap):

An approximation might be achieved by investigating the region in which the ropes lay on top of each other.



This load will result in a pressure less than case 1 above, but bending of the upper rope over the lower one would lead to larger compressive and tensile stress than that caused by pressure alone.

<u>STRENGTH OF DRUM</u>

The load intensity at the drum is 962.36 lb/in. This intensity acts over a width of .311 inch, so an equivalent pressure over the surface of the drum would be $\frac{962.36}{.311}$ = 3094 psi.

From thin walled pressure vessel theory

$$\sigma = \frac{qr}{t} = \frac{3094\ (10)}{t}$$

Assuming a mild steel with a yield strength of 38 ksi

$$t = \frac{3094(10)}{38000} = .814 \text{ inch}$$

That value is the thickness of the drum wall required to prevent yielding in the drum.

REMARKS

The theory for determining pressure q_o is based on a fairly rigid material (like a metal) with homogeneous properties. The validity of the theory is not assured when dealing with rope. If it does apply, the maximum normal stress that should be expected should be less than 100 ksi, tension and compression. This is well within safe limits for the maximum tensile stress of Kevlar 29, but its compressive properties are unknown to me. The drum strength is adequate, and the drum flange size is adequate to hold 75,000 feet of rope as long as each wrap rests into the grooves of the previous wrap.

APPENDIX A

Poison's Ratio

at 1000 lb load

Diameter = .232

Length = 10.000"

at 2000 lb load

Diameter = .230"

Length = 10.025"

at 3000 lb load

Diameter = .228"

Length = 10.05"

$$\nu = -\frac{e_{lat}}{e_{long}} = -\frac{\frac{.228-.232}{.232}}{\frac{10.05-10}{10}} = 3.45$$

E Value

Δ Load 7000 lb - 3000 lb = 4000 l[illegible]

Δ Elongation .75 - .3125 = .4375 inch

24 5/8" gage

Rope diameter (unjacketed) = .24

$$\Delta\sigma = \frac{P}{A} = \frac{4000}{\pi\frac{(.24)^2}{4}} = 88420$$

$$\Delta\varepsilon = \frac{.4375}{24\ 5/8} = .017766$$

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} = 5\text{x}10^6 \text{ psi}$$

10 F

COMPARATIVE STUDY

OF

BASIC STRENGTH CHARACTERISTICS

OF

CORTLAND AND PHILLYSTRAN ROPES

19 April 1976

OBJECTIVE

To establish the relative strengths and strength degradation of similarly rated Cortland and Phillystran ropes resulting from cyclic loading imposed on the ropes during ground tests conducted in February 1976 at White Sands Missile Range, New Mexico.

EQUIPMENT

Tinius-Olsen 120,000 Super L tensile testing machine
Nicopress aluminum crimping connectors and crimping tool

TEST DATA

1. The following test data pertains to Phillystran rope, four layers of braided Kevlar 29 with resin impregnation in an extruded polyurethane jacket, with a rated break strength of 7000 pounds.

Each test sample was 7'6" in length with three Nicopress connectors used to form an eyelet on each end of the sample. The splicing technique was identical to that used for the test data listed in the comparative study report dated 6 February 1976.

A nominal break strength was established for various sections of rope by breaking three samples and averaging the high and low break strengths of the three tests. All loading rates were slow.

Test	Break Strength (pounds)	Nominal B.S. (pounds)
Phillystran (Sample I, no prior load history)		
1	6220	
2	6500	6260
3	6020	
Phillystran (Sample II, labeled MIDDLE)		
4	6360	
5	6300	6330
6	6330	
Phillystran (Sample II, labeled END)		
7	6000	
8	6200	6215
9	6430	

REMARKS FOR PHILLYSTRAN

All failures occurred abruptly through the entire line in the splice. There does not appear to be any strength degradation due to loads imposed during field testing.

2. The following test data pertains to Cortland rope, 16 strands of Kevlar 29 wrapped into four bundles and covered with a black braided nylon jacket, with a rated break strength of 7000 pounds.

Each test sample was 6' in length. Each end was spliced with a braided splice identical to the one used on Cortland for the test data listed in the comparative study report dated 6 February 1976.

A nominal break strength was established for various sections of rope by breaking three samples and averaging the high and low break strengths of the three tests. All loading rates were slow.

Test	Break Strength (pounds)	Nominal B.S. (pounds)
Cortland (no prior load history)		
10	8500	
11	8600	8550
12	8570	
Cortland (sample labeled DRUM END)		
13	8700	
14	8400	8550
15	8550	
Cortland (sample labeled LEADER END)		
16	7900	
17	8000	
18	Flaw discovered in rope, one bundle completely separated	

REMARKS FOR CORTLAND

Equalizing tension of all strands in the splice was much easier to do. None of the splices slipped during loading. Failure occurred abruptly through one of the four bundles in the splice.

Photographs of the flaw in the rope and condition of the rope in the surrounding area have already been forwarded. It

would be difficult to determine whether this flaw was caused during the manufacturing process or by loads in the field. The rest of the rope away from this one particular area looked like new.

COMPARISON OF PHILLYSTRAN AND CORTLAND

Phillystran weighs about 30.4 pound/1000 feet while Cortland weighs 28.5 pound/1000 feet. Cortland's rope lost about 7 percent in strength and gained about 6 percent in weight due to redesign. Phillystran gained about 5 percent strength with essentially no weight change. In comparing strength to weight ratio, Cortland is still 45 percent better. However, the flaw in the Cortland would reduce its strength by an additional 25 percent.

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STRENGTH DEGRADATION OF KEVLAR 29
RESULTING FROM
EXPOSURE TO ULTRAVIOLET RADIATION

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USAF Academy

20 May 1976

1. INTRODUCTION

Cables used to tether atmospheric balloons are exposed to the surrounding environment at least for the duration of the balloon flight, and possibly for much longer time periods, depending upon how the cable is stored between flights. The effects of the environment must then be considered when selecting a cable to be used to tether balloons. Strength degradation of the cable resulting from exposure to ultraviolet could be a dominant factor in deciding whether to choose a cable made of some organic polymer. The detrimental effects of ultraviolet on nylon are already well known. The effects of ultraviolet on a relatively new product, called Kevlar, are not yet fully established. This report will consider the effects of ultraviolet on two specific cables made of Kevlar 29.

2. TEST OBJECTIVE AND PROCEDURE

The primary objective of the test program was to determine the rate of strength degradation of Kevlar 29 fibers when exposed directly to ultraviolet. Since an extensive data base on Samson braided rope and Phillystran 7x7 twisted rope (both rated at 7000 pounds break strength) was available, these ropes were used for the test.

A total of 28 Samson and 13 Phillystran test specimens were prepared for the test. Each specimen was eight feet long, cut from a continuous length of rope. Every seventh specimen was set aside as a quality control standard to be used to establish the base line for original strength of the rope. All but three Samson ropes were unjacketed. The three jacketed Samson ropes were used to determine the extent to which jacketing would reduce the rate of strength degradation.

All test specimens were sent to the Naval Aerospace Recovery Facility (NARF) at El Centro, California, for exposure. NARF masked the samples so that only two feet of the center was exposed, placed the specimens outside on 45° inclined planes facing south, and removed the specimens on the appropriate days according to our exposure schedule. Once a specimen was returned to me, I would determine the break strength of the rope by loading the rope to failure at a slow loading rate in a Tinius-Olsen standard tensile testing machine.

The end termination used for testing the Samson specimens (eyelet formed by burying a tapered tail in the core of the rope) was 100 percent efficient. The Phillystran

end termination (eyelet formed using Nicopress crimping sleeves) was not nearly as efficient, but the data is still valid for qualitative comparisons, since consistency was maintained in the way all specimens were terminated.

3. RESULTS

Table 1 lists all of the data gathered during the test. I recorded both the number of days the rope was exposed and the intensity of exposure. Intensity is the total quantity of radiant energy incident on a surface unit area expressed in the data as gram-calories per square centimeter. All specimens were placed outside on 19 May 1975. The S- designation is Samson and the P- designation is Phillystran.

Figure 1 shows a plot of break strength versus days of exposure for Samson. The upper curve is the base line curve for unexposed rope established by data from S-1, S-7, S-14, S-21, and S-28 specimens. Notice that these data points for unexposed rope have been plotted along the time of exposure axis at the same day that adjacent exposed specimens were plotted. This method gives a comparison of break strengths of exposed and unexposed ropes taken from the same region of the continuous length of rope. Previous testing with Samson rope showed that its break strength varied along the length of rope due to the way the Kevlar fibers are laid into the rope during long, continuous fabrication runs. The plot of the unexposed specimens in Figure 1 is then a more representative curve of break strength than an average of the data plotted as a constant. The curve for the exposed specimens is a best fit for the data using polynomial regression (third order).

Figure 2 illustrates the same specimens plotted as break strength versus exposure intensity. This curve is more meaningful since it eliminates the day-to-day variations of solar energy at the test site.

Figures 3 and 4 show percent strength reduction of Samson rope as a function of time and intensity. Percent strength reduction was based upon the difference in strength of the exposed and unexposed curves in Figures 1 and 2. The dip in the curve of Figure 3 is due to the use of a third order curve to fit the data well in the first 120 days, causing the curve to wiggle more in the region of sparce data.

Figures 5 through 8 illustrate the Phillystran data. Notice that the strength reduction is less for Phillystran than for Samson, possibly due to the resin impregnation

(used in fabricating the rope) helping to shield the Kevlar fibers from ultraviolet exposure.

Data from S-25, 26 and 27 indicates that no strength loss occurred in those specimens that were jacketed even though the exposure time was up to nine months, compared to S-28 which was not exposed.

4. CONCLUSIONS

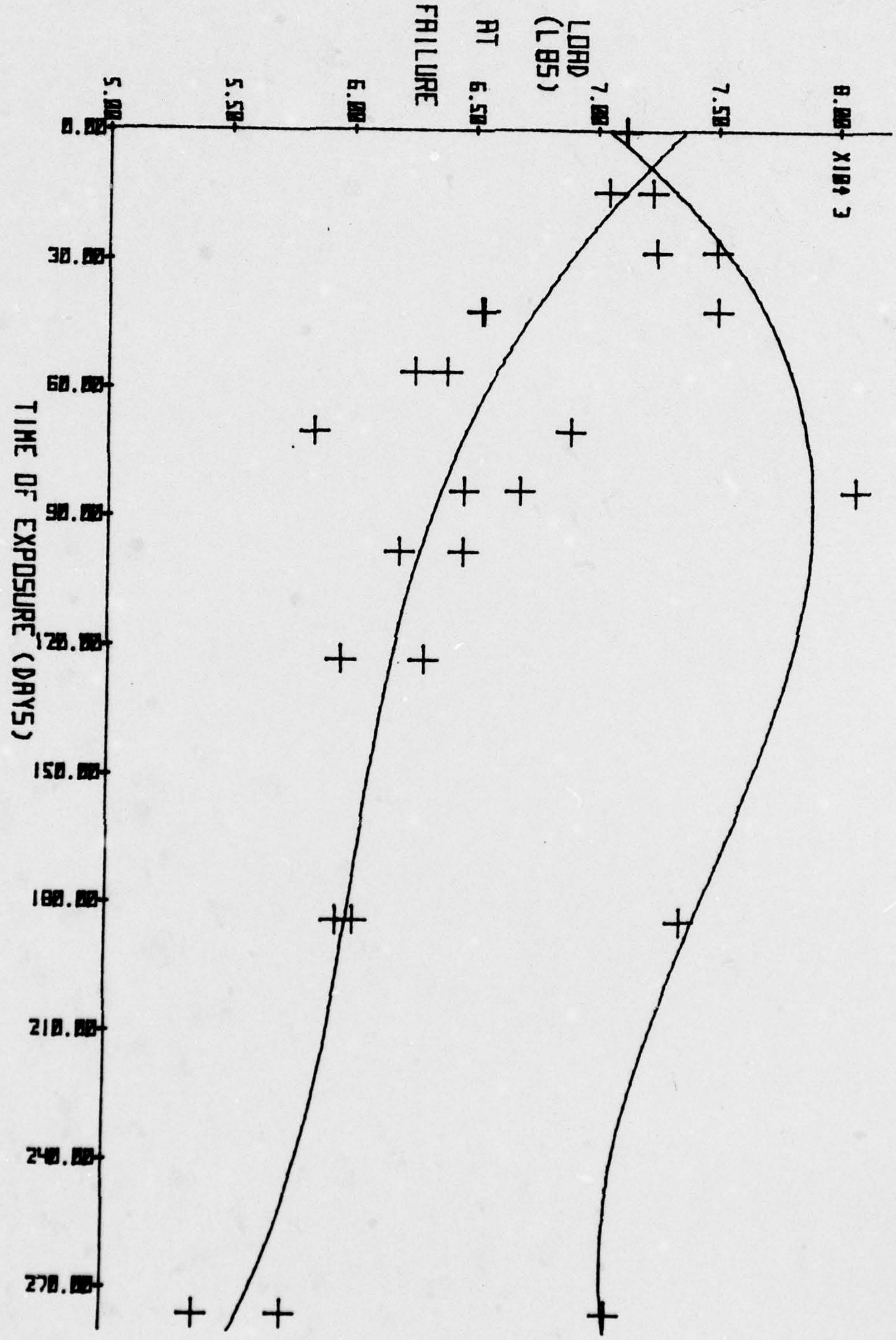
The Kevlar ropes lost about 20 percent of their strength due to exposure to ultraviolet, most of the strength loss occurring in the first three months. Jacketing the rope offers complete protection against ultraviolet effects. The reduction in rate of strength loss after 90 days could well be caused by the degraded outer fibers of Kevlar forming a protective jacket for the rest of the fibers. Resin impregnation can possibly be used to slow the rate at which strength is lost.

5. ACKNOWLEDGEMENTS

I would like to thank Major Ronald W. Obermeyer, now stationed at Wright-Patterson AFB, for his work in establishing this test program, and Mr. Jay D. Boone, Naval Aerospace Recovery Facility, for his cooperative and invaluable assistance in exposing the test specimens.

TABLE 1

Specimen	Date Removed (1975-76)	Exposure Time (Days)	Intensity (gm cal/cm^2)	Break Strength (pounds)
S-1	Unexposed	0	--	7120
S-2	2 Jun	14	9745	7050
S-3	2 Jun	14	9745	7230
S-4	16 Jun	28	21311	7250
S-5	16 Jun	28	21311	7500
S-6	30 Jun	42	29307	6530
S-7	Unexposed	0	--	7500
S-8	30 Jun	42	29307	6540
S-9	14 Jul	56	37873	6260
S-10	14 Jul	56	37873	6390
S-11	28 Jul	70	47026	6900
S-12	28 Jul	70	47026	5850
S-13	11 Aug	84	55509	6460
S-14	Unexposed	0	--	8070
S-15	11 Aug	84	55509	6690
S-16	25 Aug	98	65000	6460
S-17	25 Aug	98	65000	6200
S-18	19 Sep	123	77406	6300
S-19	19 Sep	123	77406	5960
S-20	19 Nov	184	104828	6020
S-21	Unexposed	0	--	7360
S-22	19 Nov	184	104828	5950
S-23	19 Feb	276	132614	5740
S-24	19 Feb	276	132614	5380
S-25	11 Aug	84	55509	6920
S-26	19 Nov	184	104828	7000
S-27	19 Feb	276	132614	7020
S-28	Unexposed	0	--	7070
P-1	Unexposed	0	--	5530
P-2	2 Jun	14	9745	5180
P-3	16 Jun	28	21311	4975
P-4	30 Jun	42	29307	5000
P-5	14 Jul	56	37873	5020
P-6	28 Jul	70	47026	4910
P-7	Unexposed	0	--	5610
P-8	11 Aug	84	55509	4810
P-9	25 Aug	98	65000	5060
P-10	19 Sep	123	77406	4800
P-11	19 Nov	184	104828	4640
P-12	19 Feb	276	132614	4530
P-13	Unexposed	0	--	5110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X10↑ 3
5.00
5.50
6.00
6.50
7.00
7.50
8.00
TIME OF EXPOSURE (DAYS)
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30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00

Figure 1

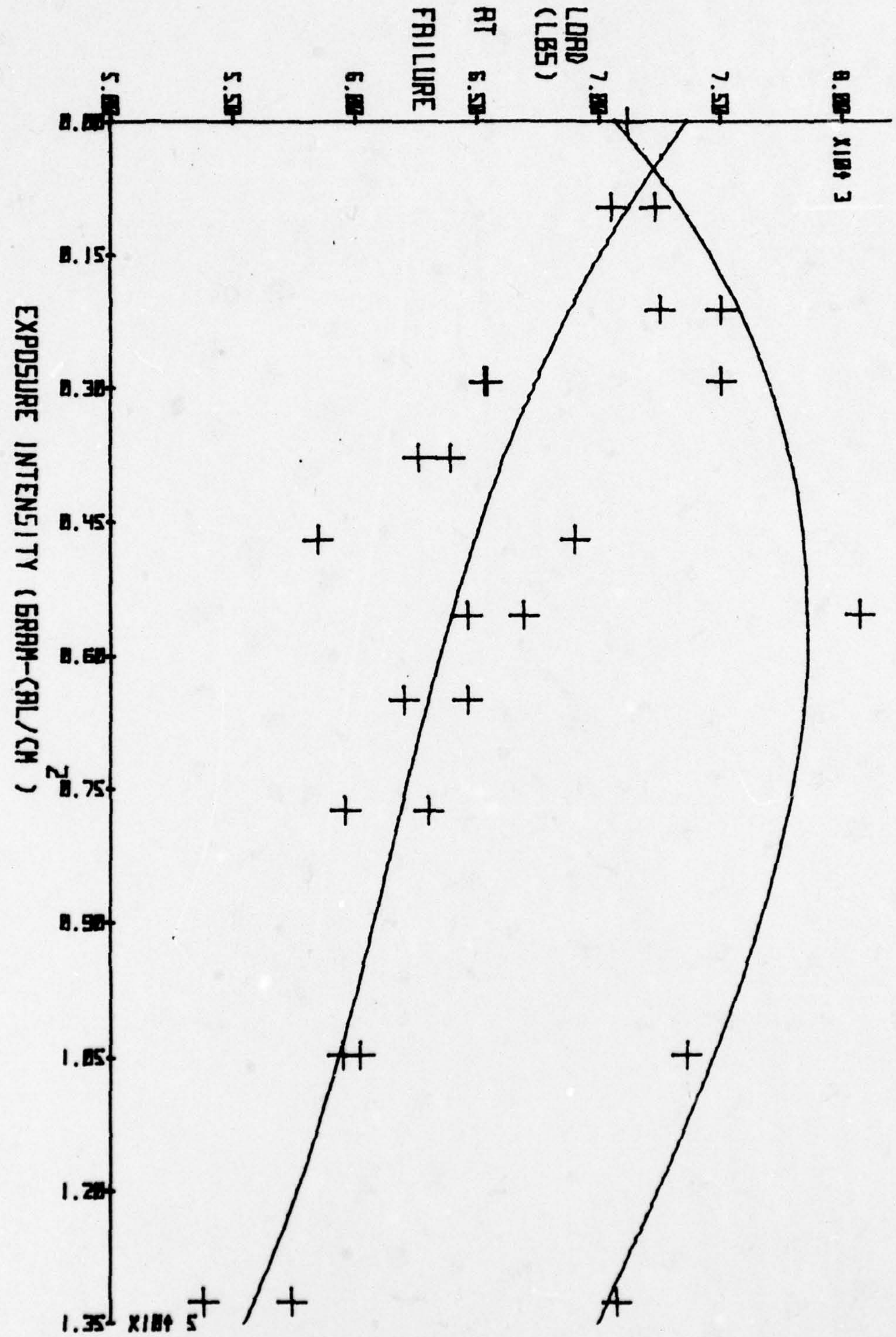
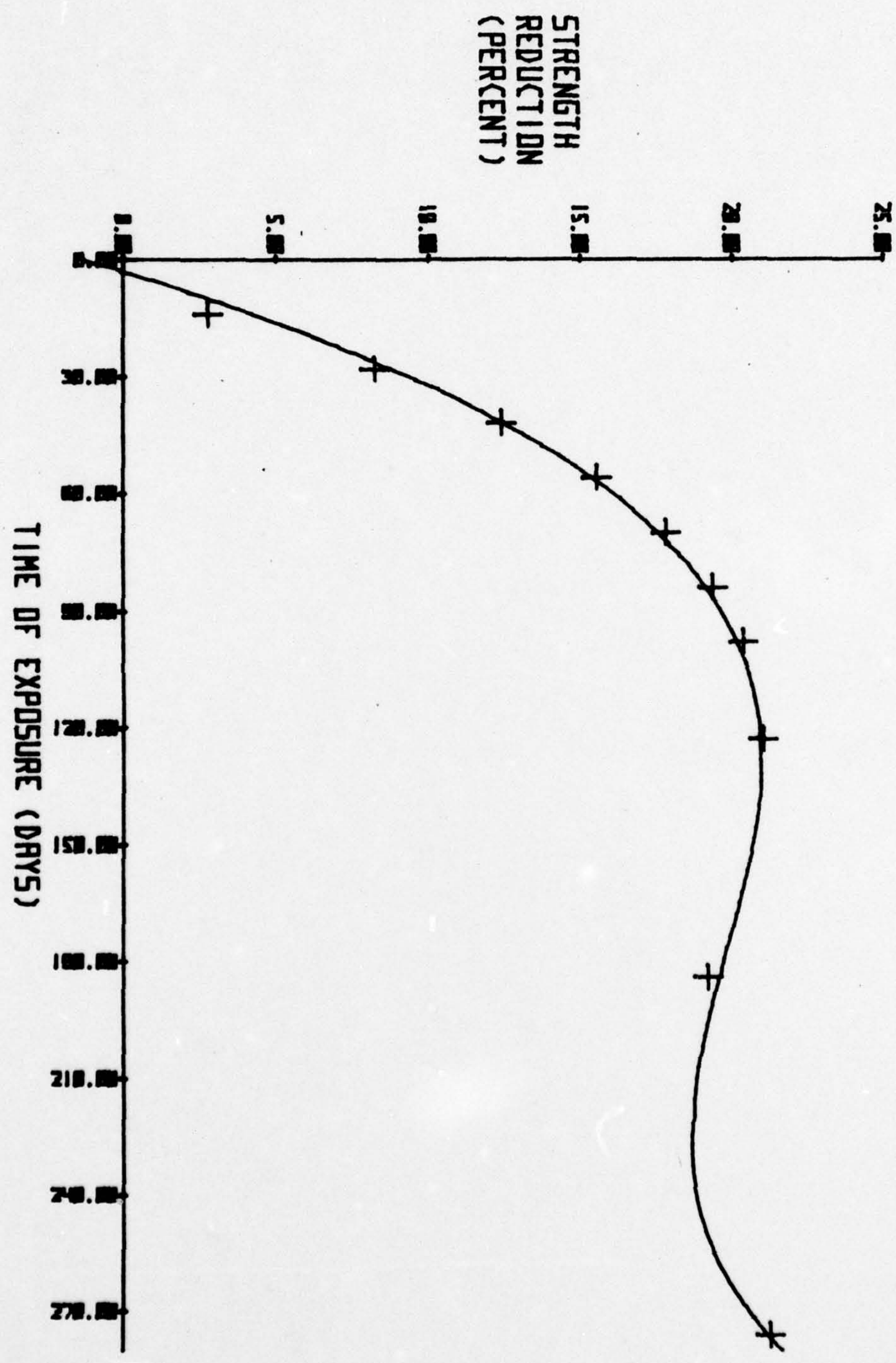

LOAD
(LBS)
AT
FAILURE
5.00
5.50
6.00
6.50
7.00
7.50
8.00 X10↑ 3
0.00
0.15
0.30
0.45
0.60
0.75
0.90
1.05
1.20
1.35 X10↑ 5
EXPOSURE INTENSITY (GRAM-CAL/CM 2)

Figure 2


STRENGTH
REDUCTION
(PERCENT)
0.00
5.00
10.00
15.00
20.00
25.00
TIME OF EXPOSURE (DAYS)
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60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00

Figure 3

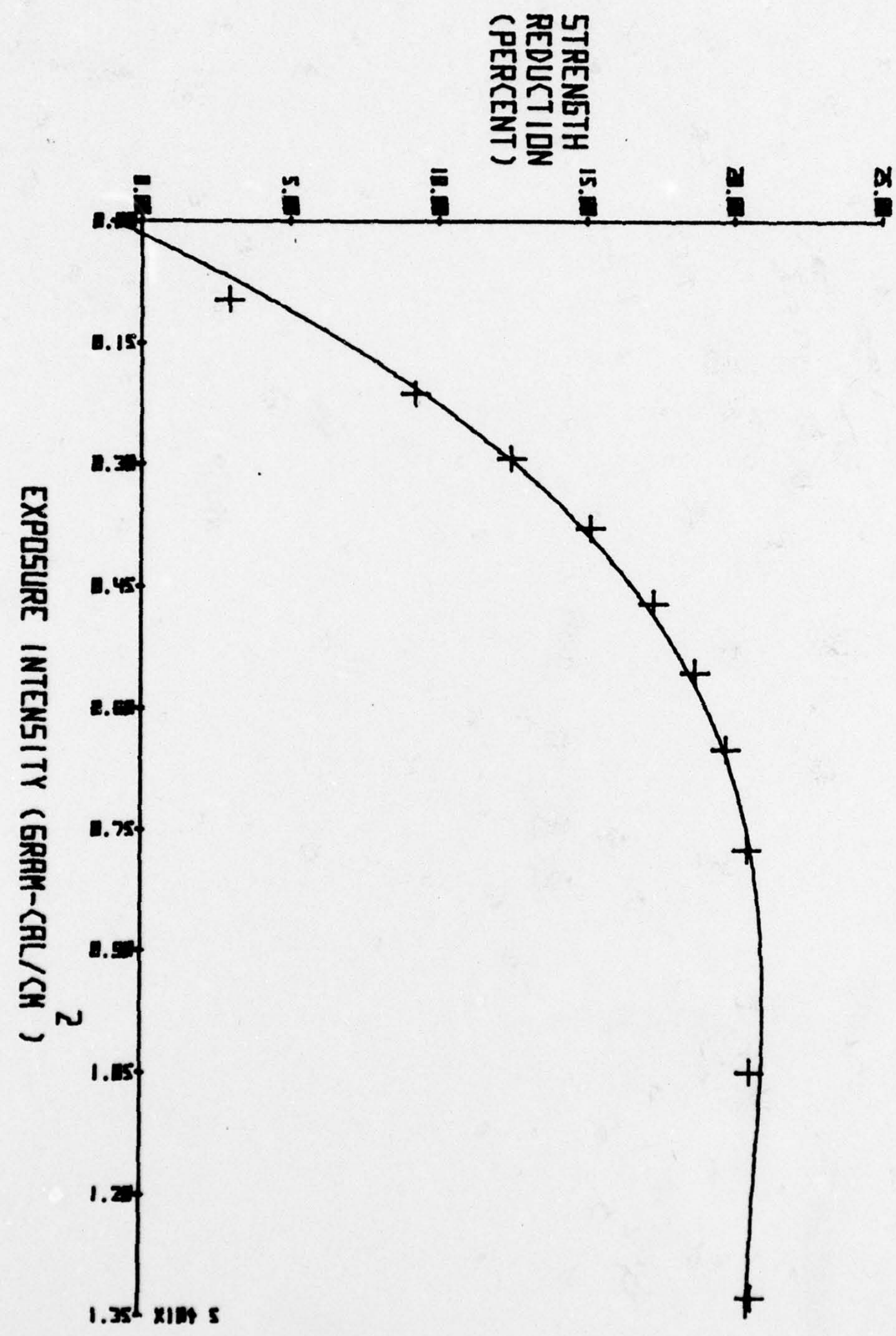

STRENGTH
REDUCTION
(PERCENT)
EXPOSURE INTENSITY (GRAM-CAL/CM 2)

Figure 4

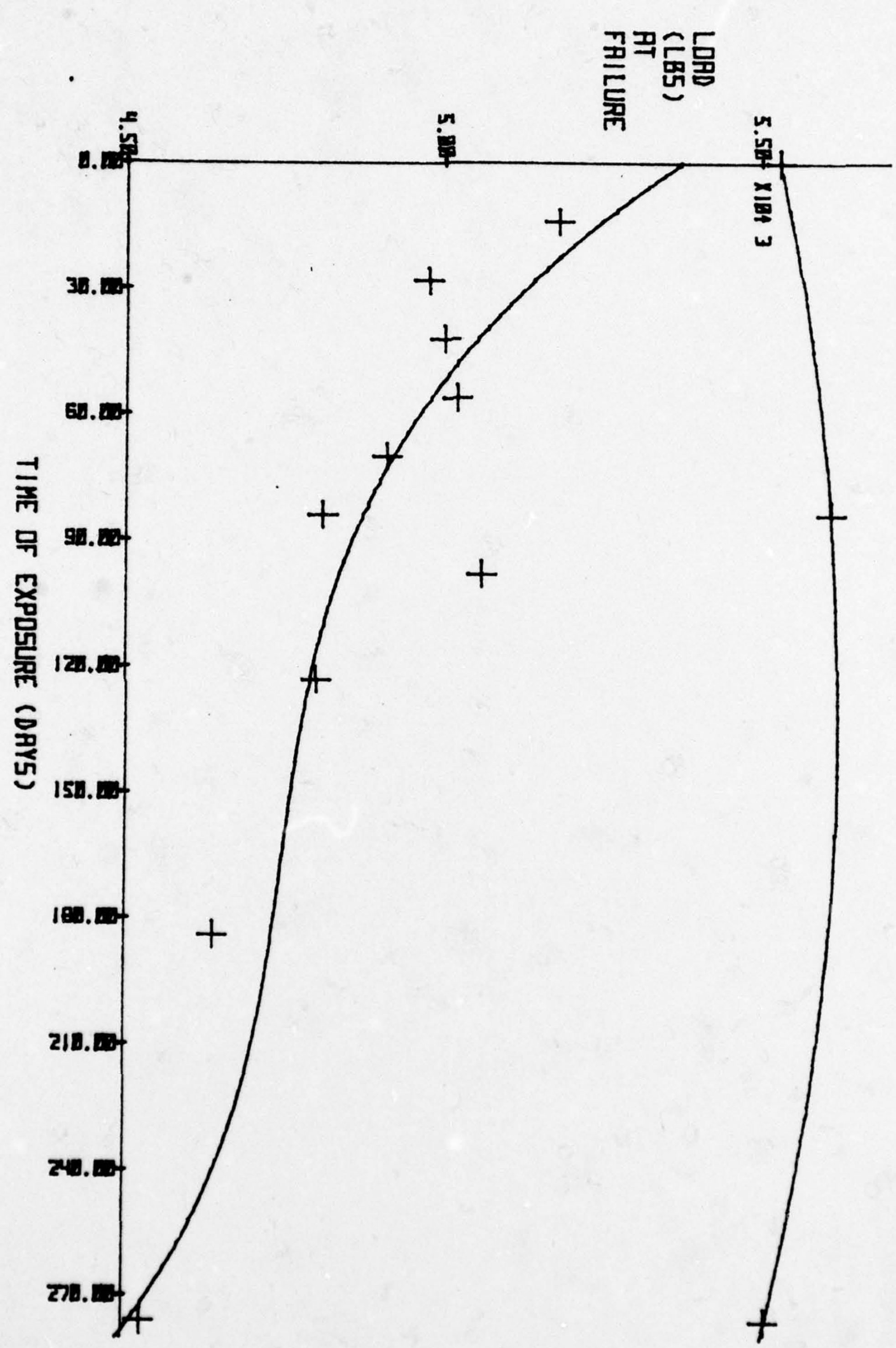

LOAD (LBS) AT FAILURE
4.50
5.00
5.50 X10^ 3
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00
TIME OF EXPOSURE (DAYS)

Figure 5

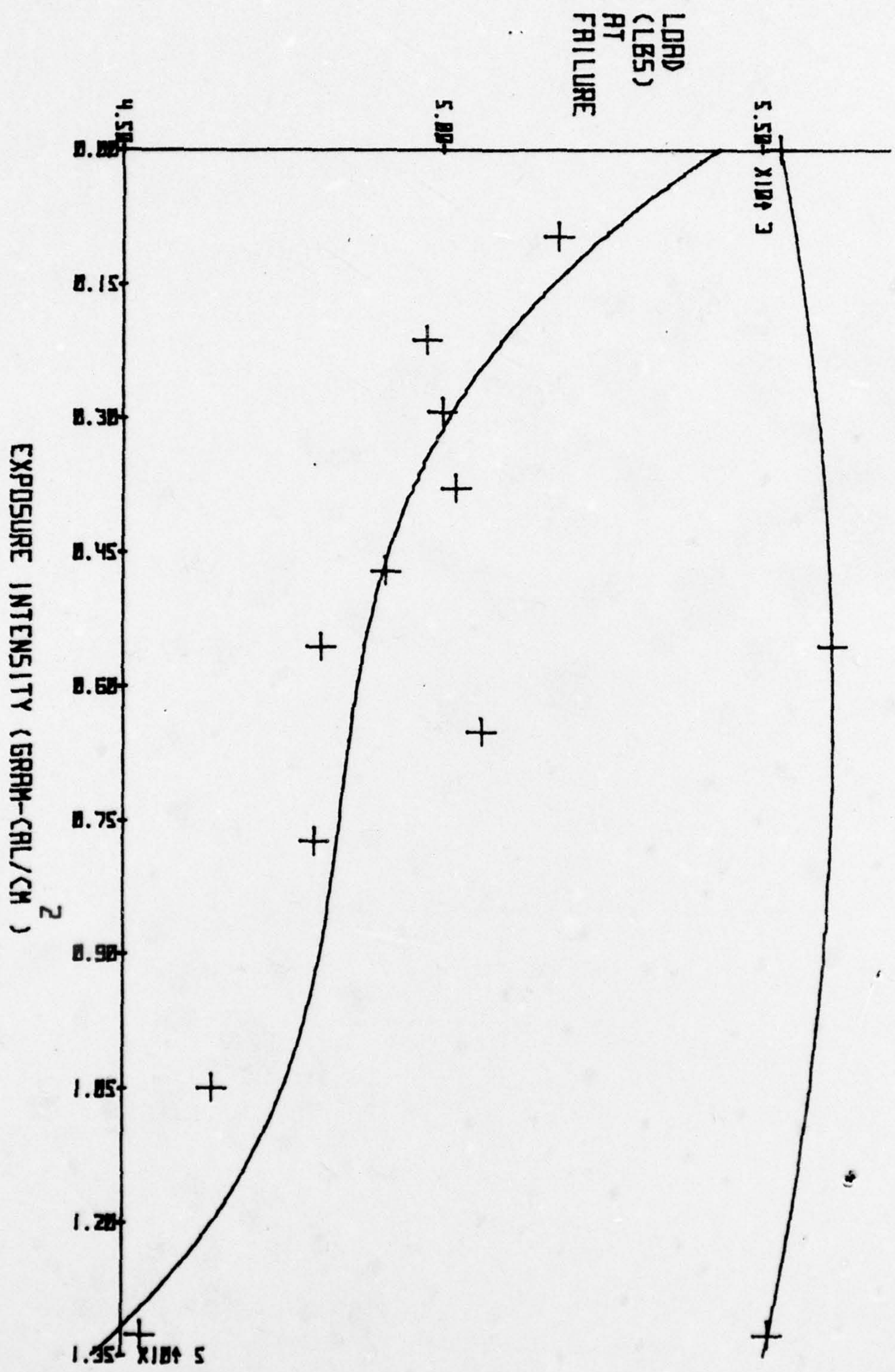
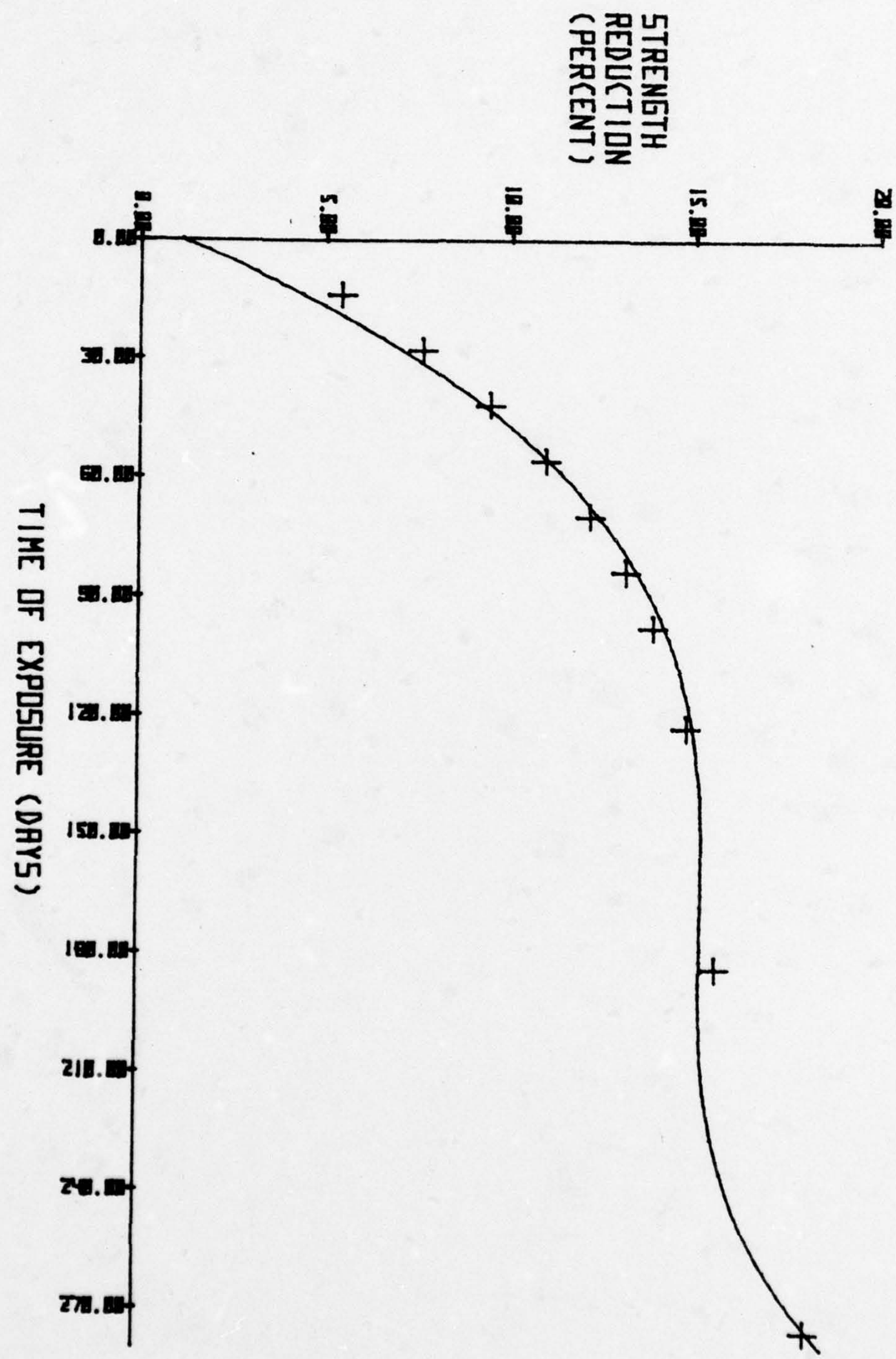

LOAD
(LBS)
AT
FAILURE
4.50
5.00
5.50 X10↑3
0.00
0.15
0.30
0.45
0.60
0.75
0.90
1.05
1.20
1.35 X10↑2
EXPOSURE INTENSITY (GRAM-CAL/CM^2)

Figure 6


STRENGTH
REDUCTION
(PERCENT)
0.00
5.00
10.00
15.00
20.00
TIME OF EXPOSURE (DAYS)
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30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
270.00

Figure 7

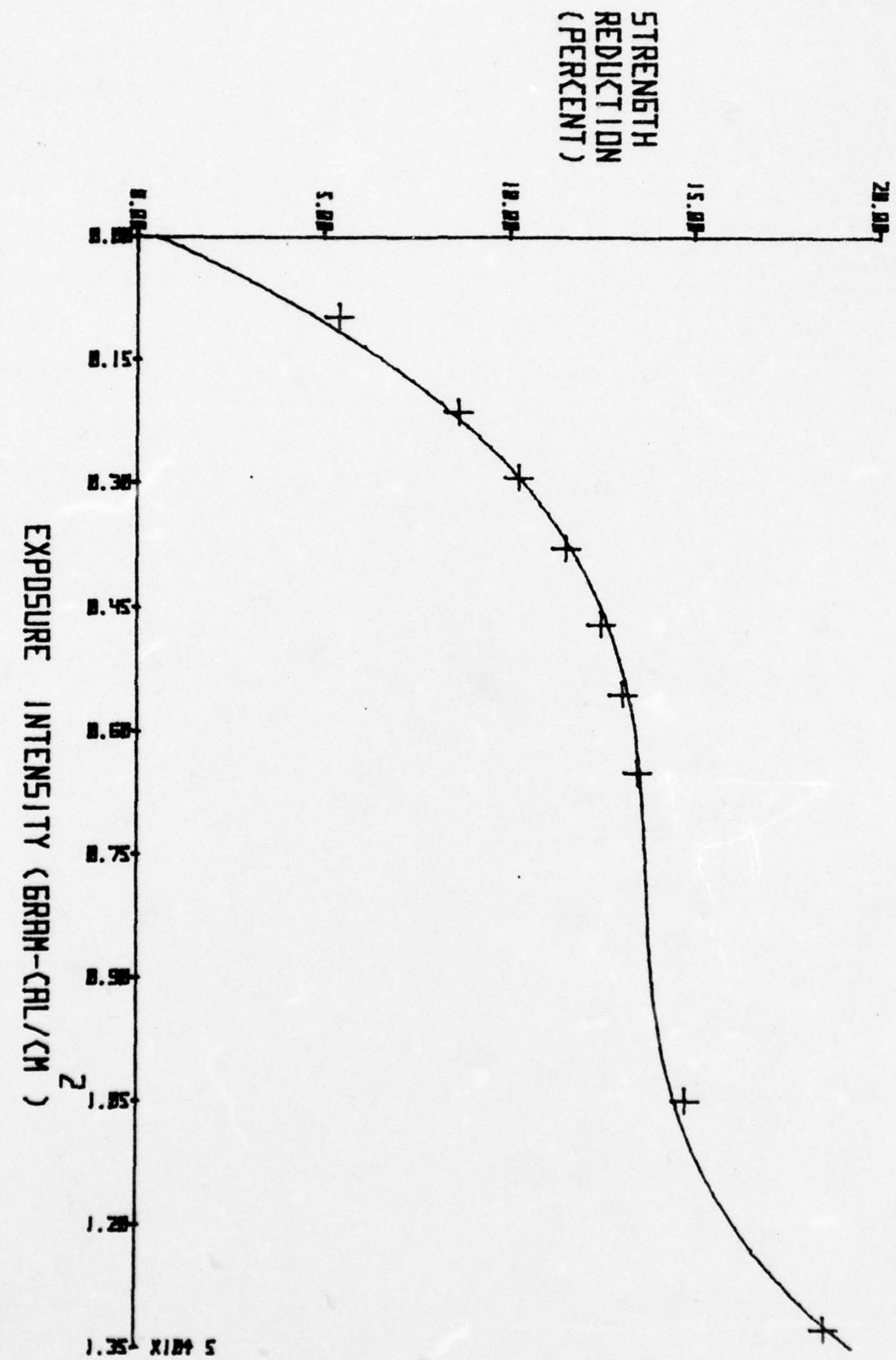

STRENGTH REDUCTION (PERCENT)
0.00
5.00
10.00
15.00
20.00
EXPOSURE INTENSITY (GRAM-CAL/CM 2)
0.15
0.30
0.45
0.60
0.75
0.90
1.05
1.20
1.35
X10* 5

Figure 8

The breaking strength tests of fifteen samples of tether line were completed on 16 June 1977. These samples w/termination were shipped to the DFCEM laboratory by the Cortland Line Co. Inc. on contract No. F19650-76-R-C040.

The samples were made up in eleven foot lengths, requiring the use of a stationary sheave fixture that has been previously used on other tether line tests. The blue markings on each line indicates the contact area of line against the sheave.

The following data was obtained from these tests.

AFT Cable #1-4 Strand

<u>Breaking Strength</u>

Test #1 - 8940 lbs
Test #2 - 8990 lbs
Test #3 - 9220 lbs
Test #4 - 8760 lbs
Test #5 - 9280 lbs

AFT Cable #1 - 3 strand

Test #1 - 7100 lbs
Test #2 - 7040 lbs
Test #3 - 6840 lbs
Test #4 - 6710 lbs
Test #5 - 6920 lbs

AFT Cable #2 - 3 strand

Test #1 - 6430 lbs
Test #2 - 6640 lbs
Test #3 - 6900 lbs
Test #4 - 7080 lbs
Test #5 - 7240 lbs

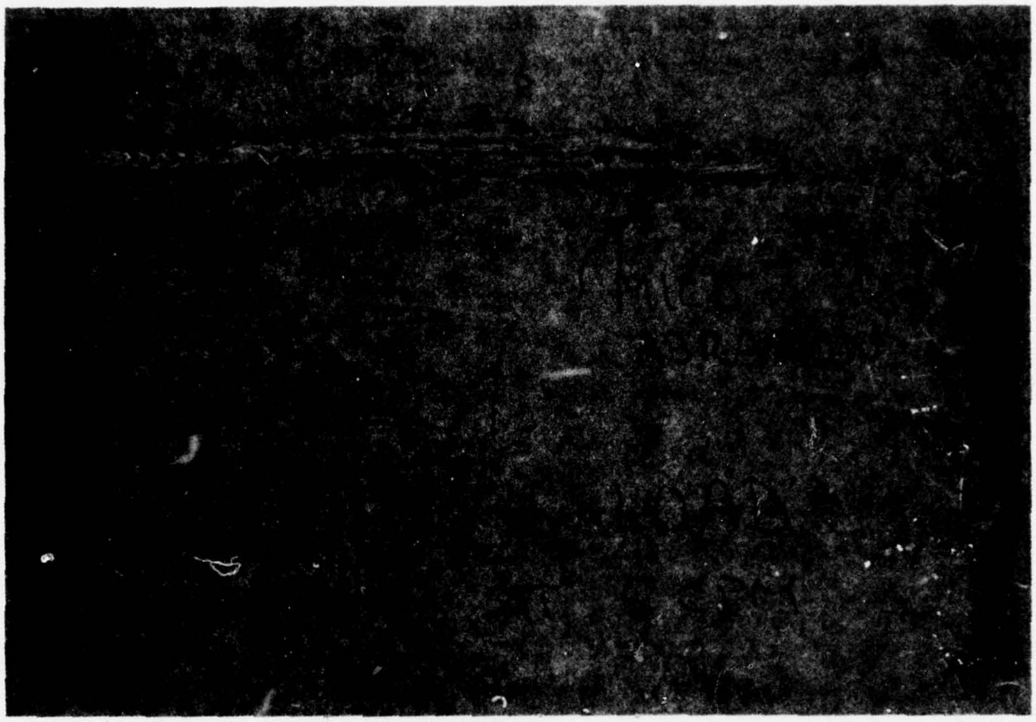


Figure A3

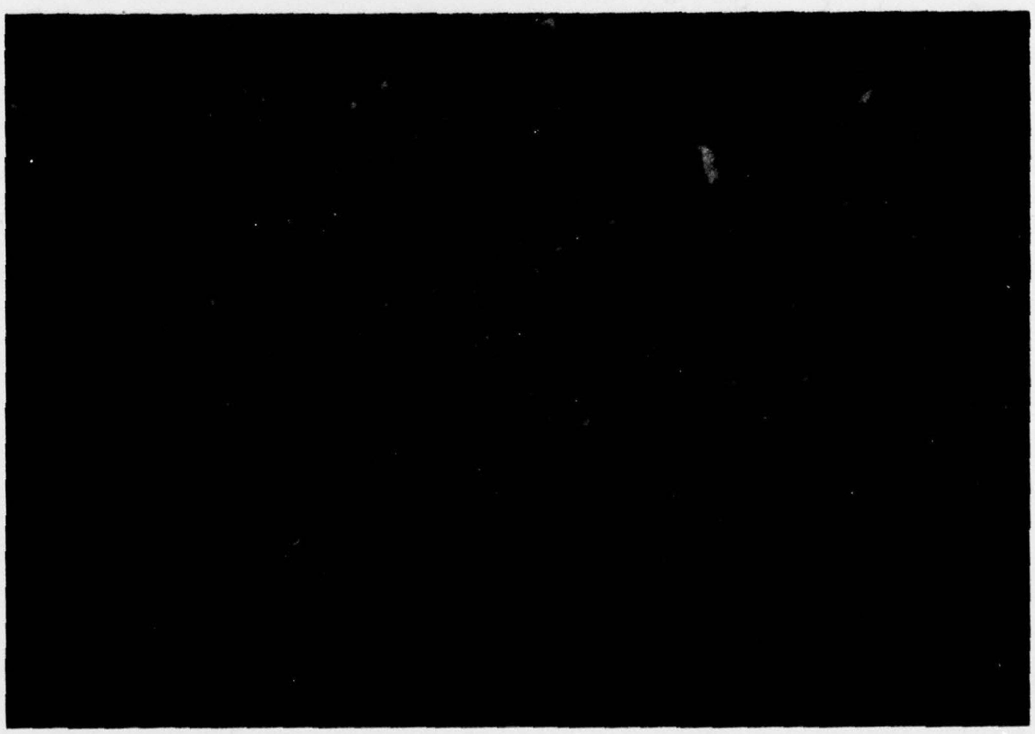


Figure A4

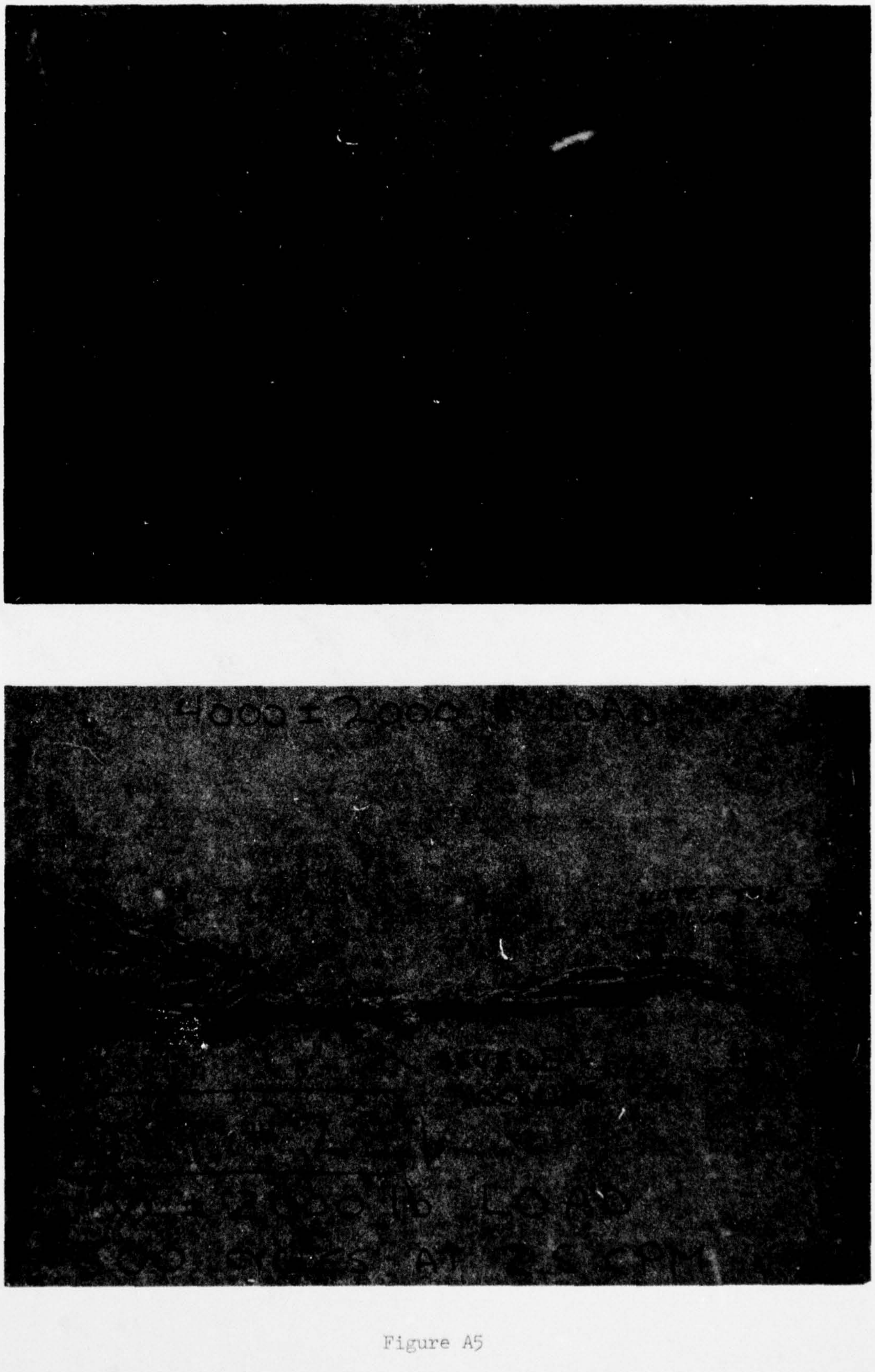


Figure A5

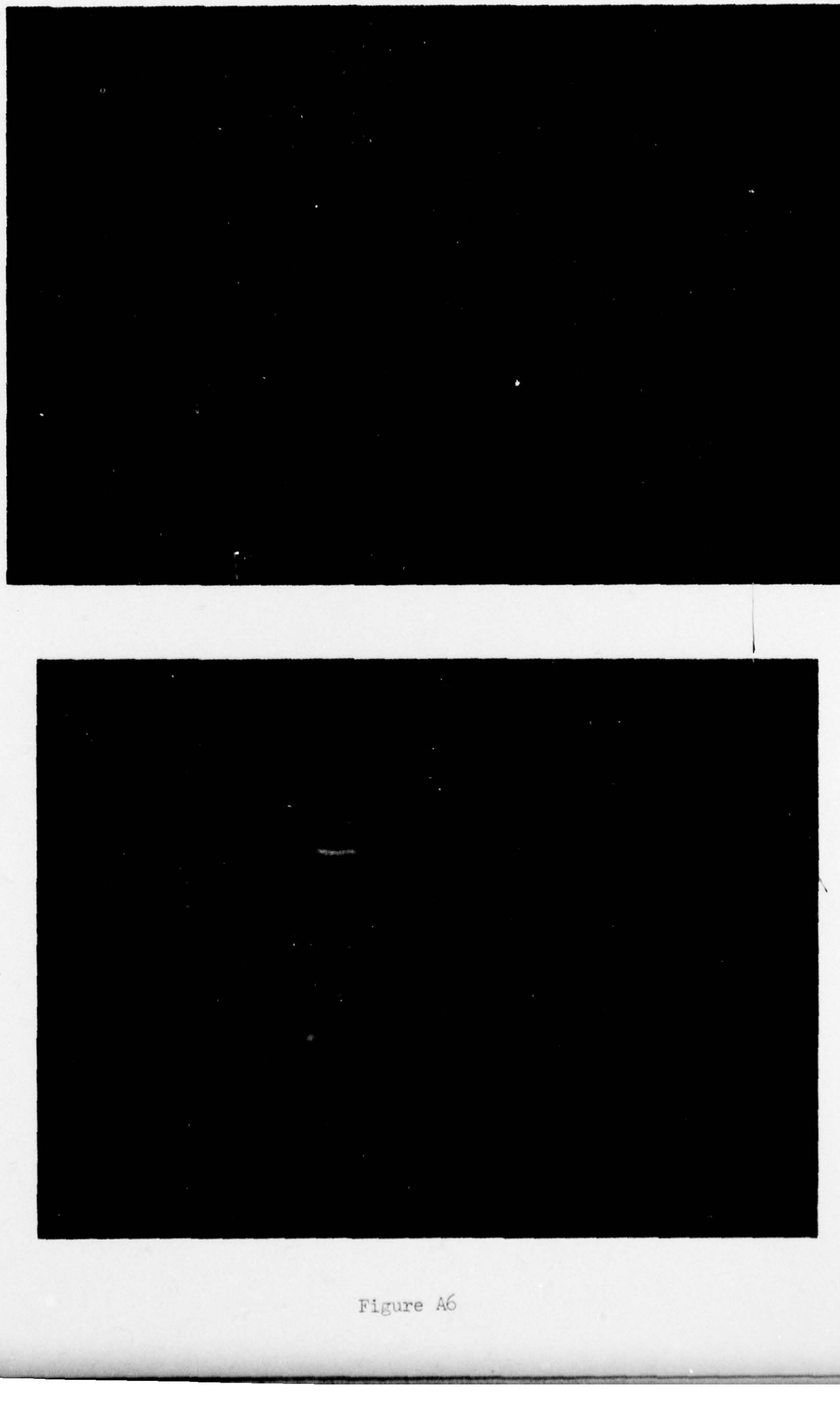
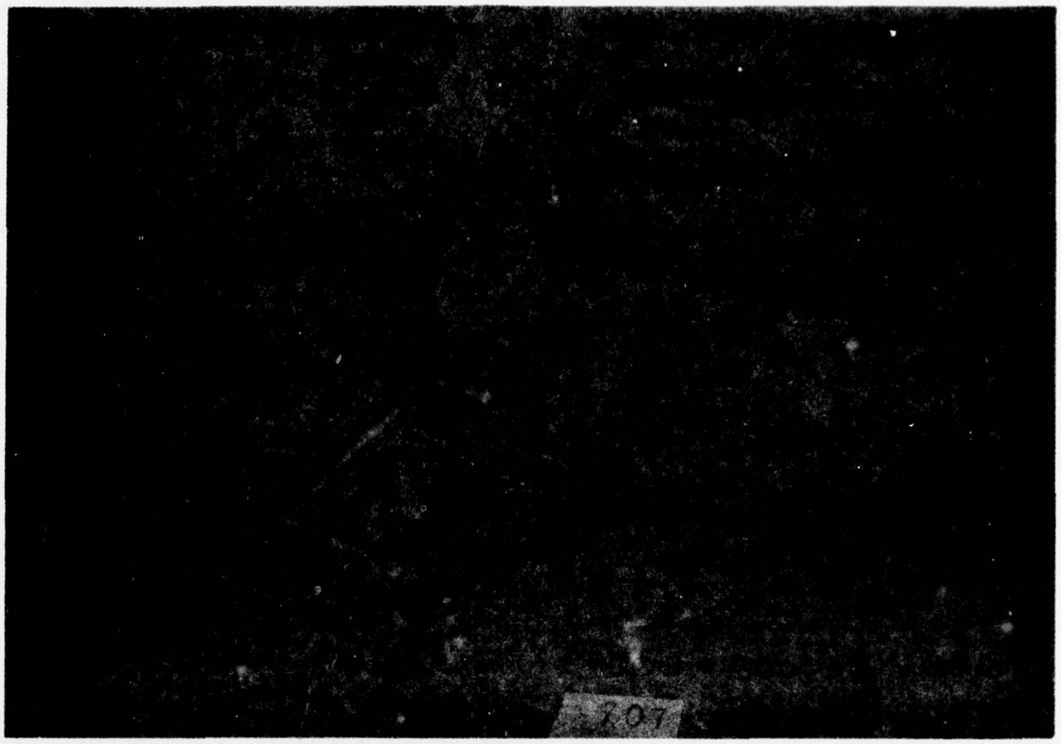


Figure A6



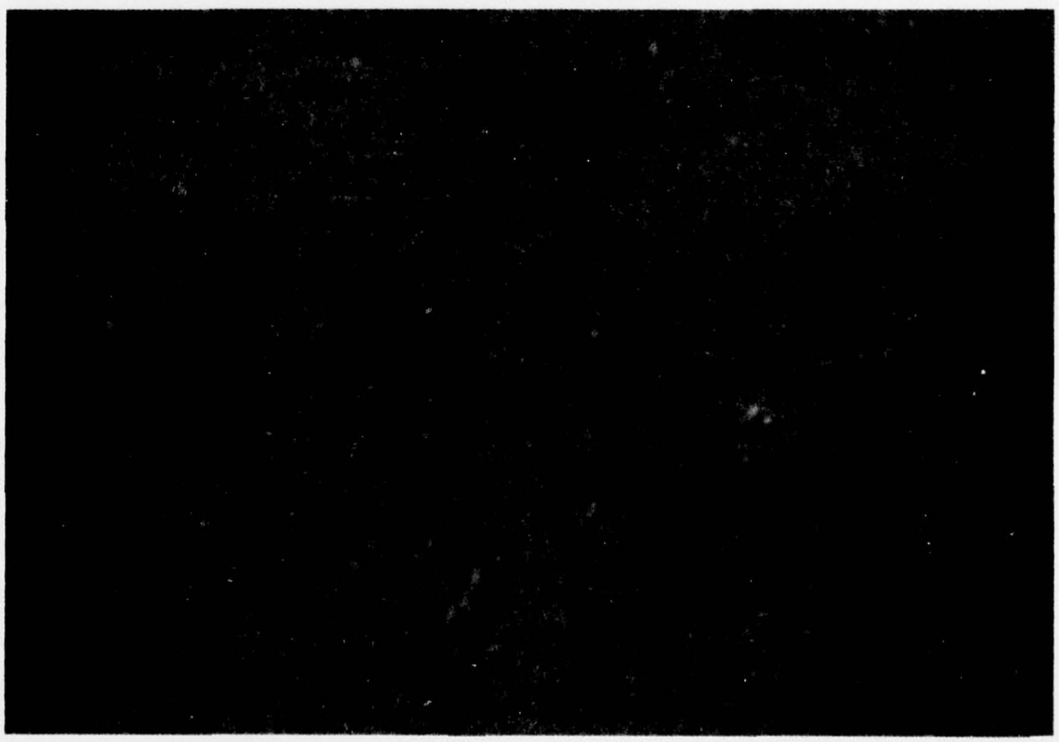


Figure A7

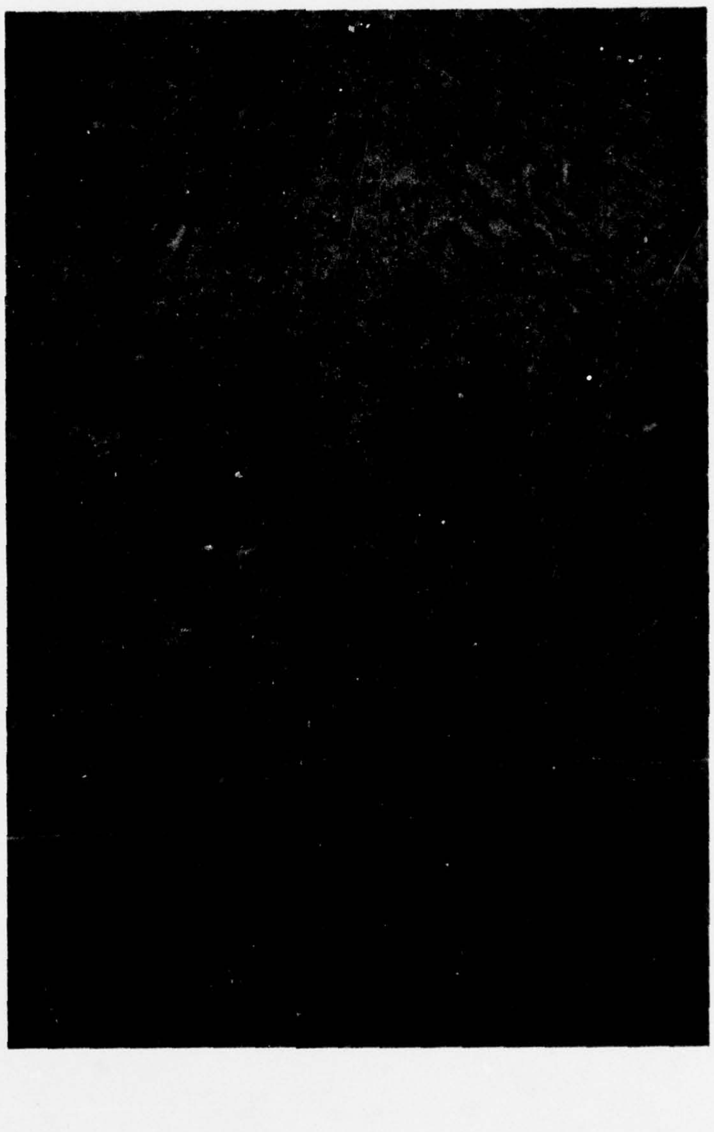


Figure A8